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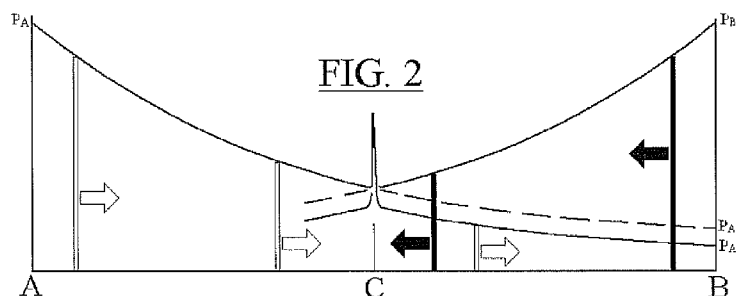
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(54) Title: SYSTEM AND METHOD FOR DETERMINING CABLE FAULT LOCATIONS OR AREAS IN AN ELECTRIC HEATING CABLE



(57) **Abstract:** Method for determining cable faults in an electric heating cable comprising at least two well conductor lines having an electrical resistor material in between them and electrically connected to the conductor lines in order to dissipate power over mainly the whole length of the cable when connected to an electric power source. Such cable fault may be caused by electrical disconnection between the resistor material and the conductor lines, resulting in interruption of the power dissipation there. The method comprises the steps of a. sending an electrical signal having a predetermined electric power P_A , from a location A to a location B of the cable and determining the power P_A' of the signal arrived at location B, b. sending an electrical signal having the predetermined electric power P_A , from location A at a moment T_1 , as well as sending an electrical signal in the opposite direction having a predetermined electric power P_B from location B at a moment T_B which is chosen such that the first signal and the opposite signal meet each other at a predetermined location C between the locations A and B, and determining the power P_A'' of the signal arrived at location B, c. comparing the power P_A'' of the signal arrived at location B determined in step b. with the power P_A' of the signal arrived at location B determined in step a. and concluding either that if P_A'' is lower than P_A' , location C is not faulty, or if P_A'' is not lower than P_A' , location C is faulty.

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Title: Method for determining cable fault locations or areas in an electric heating cable

Field of the invention

The present invention concerns a method for determining one or more cable fault locations or areas in an electric heating cable,

5 Background

A heating cable may comprise at least two conductor lines (well conductive lines) and electrical resistor material in between the conductor lines, electrically connected to the conductive lines over mainly the whole length of the cable, in order to produce heat over mainly the whole length of
10 the cable when connected to an electric power source. As used herein, mainly the whole length leaves open feed parts of the cable without the electrical resistor material, intermediate cable interconnections without such material and other intentional local interruptions of the material for example at locations where no heating is needed. A cable with resistor material over
15 mainly the whole length leaves has such material at least half its length and preferably over more than 90% of the length.

Such heating cables are generally known. The cables may be used to keep e.g. pipes, valves, tanks etc. in chemical plants, fluid distribution systems etc. at a desired (minimum) temperature, e.g. in order to secure that fluids
20 flowing through those pipes, valves etc. remain liquid, in order words, that those fluids will not coagulate or freeze due to too low temperature. For that reason the heating cables are wound around or otherwise connected with the relevant pipes etc. For the sake of heat isolation, the pipes etc. (including their heating cables) will normally be surrounded by an isolation layer of e.g. rock or
25 glass wool, which layer can be covered by e.g. an aluminium shielding.

The heating cable normally comprises two or more conductor lines and an electrical resistor material in between the conductor lines and

electrically connected to the conductive lines in order to dissipate power over mainly the whole length of the cable when connected to an electric power source. In practice, however, faults may occur in the heating cables when, at certain locations or areas, the electrical resistor material in between the
5 conductive lines loose their (electrical) contact with the conductive lines. Due to this the heating cable will not dissipate any power in those faulty locations or areas as no electrical current is able to flow through the resistor material in those locations or areas where the electrical connection is interrupted.

Due to the fact that the heating cables normally will be covered by
10 isolation material, fault locations cannot be detected from the outside of the isolated pipes, valves etc., causing that faulty (i.e. not heated) locations and areas cannot be detected. Moreover, when it appears that e.g. the throughput of a pipe section decreases, which could be blamed on malfunctioning of the relevant heating cable, until now no useful methods exist to determine –
15 without dismantling the relevant pipe section's isolation and cover layer– at which location(s) the heating cable is faulty, so that the isolation layer and cover has to be removed over the whole pipe section.

US 5,270,661 describes a method of detecting anomalies in pipelines by means of synchronized pulses from two ends. An example of testing coaxial
20 cables is mentioned. The document mentions detection of damage to an isolation layer, interruptions of the conductor, changes in pipe thickness and changes in surrounding soil. Application to detection of faults in heating cables, wherein pulse interactions occur substantially everywhere along the cable because conduction between the conductors is present along most of the
25 length of the cable even absent faults, is not described.

Summary

It is an object to provide a novel method for determining one or more cable fault locations or areas in an electric heating cable.

Another object is to provide such method which is not based on signal reflection time measurement, known as such, but which kind of measurement is not appropriate as, due to the significant cable resistance – inherent to heating cables– (reflection) signals will extinguish very rapidly, causing that no well recognizable reflection signal can be detected.

Moreover, it is found that in practice more reflections signals (all being extremely weak) occur, causing that fault locations in the heating cable cannot be determined with any serious certainty. Besides, reflection time measurements only would be able to give an indication of variations in the impedance of the cable, i.e. would only indicate the begin and the end location of a faulty cable area. Therefore it is also desirable to provide a method which determines all individual locations at which the resistor material between the conductive "power feeding lines" of the heating cable has become disconnected from one or both power feeding lines, causing an interruption of the power dissipation in those faulty locations or areas.

A method is provided wherein the following steps are performed (steps a. and b. to be performed in any order):

a. sending a first electrical pulse signal having a predetermined electric power P_X , from a location X (A or B) to a location Y (B or A respectively) of the cable and determining the power P_X' of the signal arrived at location Y;

b. sending a second electrical pulse signal having said predetermined electric power P_X , from location X at a moment T_X , as well as sending a further electrical pulse signal having a predetermined electric power P_Y in an opposite direction from location Y at a moment T_Y which is chosen such that the first signal and the opposite signal meet each other at a predetermined location Z between the locations X and Y, and determining the power P_X'' of the signal arrived at location Y;

- c. comparing the power P_X'' of the signal arrived at location Y determined in step b. with the power P_X' of the signal arrived at location Y determined in step a. and concluding either that
- if the power P_X'' determined in step b. is lower than the power P_X' determined in step a., location Z is not faulty, or
 - if the power P_X'' determined in step b. is not lower than the power P_X' , location Z is faulty. Herein pulse signals are signals formed so the signals have a pulse shape at their meeting location Z. Alternatively the power P_X' determined in step a. may be replaced by a reference power value. Such a value may be predicted for example by a computation based on a model for a faultless cable. However, use of a measured reference makes the detection more reliable.

Suppose that an electric pulse having an electric power P_X is sent at a moment T_X from one end X of a "suspicious" section of a heating cable. At each subsequent moment T_L the pulse will –provided that the cable is in good order– dissipate power at cable location L which is proportional with $U_{L(X)}^2$ (viz. $P_{L(X)} = U_{L(X)}^2 / R_L$), in which $P_{L(X)}$ is the electric power at location L caused by the pulse P_X launched at location X, $U_{L(X)}$ is the electric voltage over the feeding lines caused by pulse P_X and R_L is the electric resistance between the feeding lines at location L).

Suppose, furthermore, that another pulse is sent from the opposite end Y of the cable section at the same moment ($T_Y = T_X$), hereinafter called "opposite" pulse or signal, and the opposite electrical signal having an electric power P_Y which is equal to the power P_X of the first pulse. At each subsequent moment the pulse –running in the direction opposite to the running direction of the first pulse– will likewise dissipate a power which is proportional with $U_{L(Y)}^2$ (which is equal to $U_{L(X)}^2$ as P_Y is equal to P_X).

As both pulses are sent at the same moment $T_X = T_Y$ from the opposite cable ends, they will meet in the middle of the cable section and

fortify each other such that the power dissipation in that meeting point Z will rise fourfold, viz. because both voltages, $U_{Z(X)}$ (i.e. the voltage in Z caused by the pulse launched in X) and $U_{Z(Y)}$ (i.e. the voltage in Z caused by the pulse launched in Y) will be added one another, causing that $U_Z = U_{Z(X)} + U_{Z(Y)} = 2 * U_{Z(X)}$ ($= 2 * U_{Z(Y)}$) and thus $P_Z = (2 * U_{Z(X)})^2 / R_Z = 4 * U_{Z(X)}^2 / R_Z = 4 * P_{Z(X)}$. As this power is dissipated by two pulses (viz. the first pulse and the opposite pulse), at the meeting location Z the power dissipation per pulse (assigned to each pulse) is twice compared with the power dissipation at all other locations of the cable.

As will further be elucidated graphically hereinafter, the meeting (or crossing) of both pulses, sent from end X and end Y respectively, thus will cause extra power dissipation at meeting location Z. This extra power dissipation thus will cause a dip in the power course of the pulse, travelling further from point Z towards its end point Y, which dip can be detected at the other side Y of the cable, viz. by comparing the power P_X'' (i.e. the remaining power of the pulse sent from location X) measured at location Y, with the power P_X' measured at location Y when no (opposite) electric pulse would be transmitted from location Y towards location X (thus causing no voltage doubling at any meeting point between X and Y).

So, when Z is a location in which the heating cable functions faultless (i.e. the resistor material is well connected to the feeding lines), a relative power dip of the pulse sent from location X can be detected at location Y, which power dip can be measured by measuring the power P_X'' of the remaining pulse at location Y and comparing it with a previously (or afterwards) determined level P_X' of the remaining pulse at location Y when no opposite pulse was launched from location Y.

When, however, Z would be a location in which the heating cable functions faulty (i.e. the resistor material is disconnected from the feeding lines), no power dip of the pulse sent from location X will be detected at location Y (i.e. the power P_X'' of the remaining pulse at location Y will be equal

to or even higher than the previously or afterwards determined level P_X' . The reason is that, although the summed voltage in the (now faulty) meeting location of both pulses, originated from locations X and Y respectively, is twice the voltage caused by each individual pulse, however, no extra power
5 dissipation will occur –which would cause a power dip– as, since the resistor material is disconnected from the feeding lines at location Z, the electrical current will not be able to flow through the resistor material there and thus no power dissipation will occur at location Z at all, due to which the pulse power will not decrease at all at location Z (and in every faulty location or area). So,
10 instead of causing a power dip, the power level of the pulse(s) travelling through a faulty location or area will remain constant. As a result of this at the "upstream" end Y (upstream for the pulse originated at location X) it can be measured that the power level P_X'' of the pulse received from location X is not lower than the previously (or afterwards) measured level P_X' without an
15 opposite pulse travelling from Y towards X.

In this way it can be detected whether the location Z is faulty or faultless. It will be understood that the location Z of the meeting point of the mutual opposite pulses can be varied by varying the moments T_X and T_Y at which the mutually opposite pulse are "launched" at the cable ends X and Y
20 towards their opposite ends Y and X respectively, or rather by varying the time difference between T_X and T_Y , i.e. their period $p_{X,Y}$, from $-t_{XY}$ to $+t_{XY}$ –where t_{XY} is the electrical transit time for a signal to travel from X to Y or *vice versa*– the location Z of the meeting point of the oppositely travelling pulses can be set and, by doing so, all locations Z between X and Y can be checked for a fault in
25 the connection of the resistor material with the feeding lines.

In each of such measurement of the local cable condition, at subsequently varying pulse meeting locations Z, it may thus either be concluded that, if the power P_X'' is lower than the power P_X' , the investigated location Z is not faulty, or reversely, it may be concluded that that if the power
30 P_X'' is not lower (i.e. equal or higher) than the (previously or subsequently

measured) power P_X' , location Z is faulty. By e.g. plotting or any other graphical display of the results for the varying locations Z from location X to location Y, a reliable image can be made of the condition of the complete cable section X-Y, which enables to determine the fault locations or areas of the heating cable attached to the relevant e.g. pipe section to be heated, after which only the pipe isolation layer needs to be removed in order to replace the faulty heating cable part by a new, faultless cable part, thus preventing to be forced to remove the pipe isolation over a considerably larger area.

As said before, it is preferred that the method steps are repeated using different values for the period $p_{X,Y}$ between T_X and T_Y ranging from $-t_{XY}$ to $+t_{XY}$ (t_{XY} being the signal running time). Furthermore, it is preferred to register and/or display, for the relevant values of the period $p_{X,Y}$ and the resulting values of the meeting location Z, for which values of Z location Z is deemed to be faulty and for which values of Z location Z is deemed to be not faulty.

Preferably, the powers P_X and P_Y are chosen so that the power $P_{Z(X)}$ at location Z caused by the signal sent from location X and the power $P_{Z(Y)}$ at location Z caused by the signal sent from location Y have substantially the same order of magnitude and more preferably equal values. This will cause that the sum of the voltages of the meeting (or crossing) pulses in the meeting location Z always has about the double value of the voltage cause by one single pulse, which will give an optimal dip value in the course of further travelling pulse(s). To work towards the enable this preference, the transmitted powers P_X and P_Y are adapted dependent on distances to the location Z so that a first ratio between the transmitted power P_X and P_Y is adapted dependent on the distances, and a second ratio of power levels of the signals at the location Z due to of the signals transmitted in opposite directions is changed in the direction of a ratio of one, compared to a value of the second ratio if equal power levels would be used for the signals transmitted in opposite directions. In an embodiment the powers of both opposite pulses, sent from X and Y

respectively, are chosen equal one another, but if the meeting location Z is set –by choosing appropriate pulse transmission moments T_X and T_Y – e.g. is chosen more towards the location of X, the power P_Y of the pulse transmitted from location Y is chosen accordingly larger than the power P_X of the pulse transmitted from location X, as the pulse from Y will experience, due to the relative larger distance from Y to Z than from X to Z, more damping (mainly due to the resistor material between the feeding lines) of the "opposite" pulse sent from location Y. Reversely, if location Z –set by the difference of T_X and T_Y (i.e. the absolute value of $p_{X,Y}$)– is more towards location Y, the power P_X of the pulse transmitted from location X has preferably to be set accordingly larger than the power P_Y of the pulse transmitted from location Y.

If meeting location Z is closer to location Y than to location X, P_X has to be larger than P_Y in order to obtain the preferred situation that pulse $P_{Z(X)}$ has approximately the same power as pulse $P_{Z(Y)}$. In that case also P_X' will be larger than P_Y' . On the other hand, if location Z is more close to X than to Y, P_Y' has to be larger than P_X' . Therefore in the latter case it is preferred in steps a. to c. to consider location X as being location Y and vice versa (in other words to exchange locations X and Y. This will make that when meeting location Z is closer to location Y than to X, the (detected) signal levels of P_X' and P_X'' are rather large (compared with the signal levels of P_Y' and P_Y''), which will lead to a decrease of the measurement uncertainty. In an embodiment the powers P_X and P_Y are chosen so that a ratio of the power $P_{Z(X)}$ at location Z caused by the signal sent from location X and the power $P_{Z(Y)}$ at location Z caused by the signal sent from location Y is changed towards a value of one, compared to the value of that ration when equal transmitted powers are used. In a further embodiment this ratio is made equal to one. By making the ratio closer to one, measurement uncertainty is decreased.

To counteract any pulse distortion caused by the heating cable's signal transmission characteristics), which would cause both opposite pulses to appear at their meeting location Z having a rather indefinite shape –which

might make the findings about the location Z less certain—, it may be preferred that the signals sent from locations X and Y respectively are formed —e.g. processed in their frequency domain or using any other method well known as such in the art of signal transmission— such that both signals have a well
5 defined and definite pulse shape at their meeting location Z.

In an embodiment the roles of the locations X and Y are interchanged, dependent on the location Z, the conclusion that location Z is faulty or not being determined from power determined at location X for locations Z in a first range and from power determined at location Y for a
10 second range of locations Z. The ranges may be ranges on respective sides of a mid point of the heating cable. Measurement be used from the detector that is closest to the range in which the location Z lies, that is, on the side of the heating cable closest to the location Z. This improves reliability

A system is provided arranged for performing the novel method as
15 presented in the preceding.

Brief description of the drawing

These and other objects and advantageous aspects will become apparent from a description of exemplary embodiments using illustrative
20 figures. Location X, mentioned in the preceding, may correspond either to location A or to location B in the following figures. In the same way location Y, mentioned in the preceding, may correspond either to location B or to location A respectively. Both locations A and B may be considered equivalent. Location Z, mentioned in the preceding will be called location C in the following figures.
25

Figure 1 shows a diagram illustrating the power of one pulse travelling between two locations A and B of a faultless heating cable;

Figure 2 shows a diagram illustrating the powers of two opposite pulses travelling along a faultless cable from locations A to B and from

locations B to A respectively and meeting in a meeting location C in between locations A and B;

Figure 3 shows a diagram illustrating the powers of two opposite pulses travelling along a faultless cable from locations A to B and from
 5 locations B to A respectively and in a meeting location C more towards location B.

Figure 4 shows a diagram illustrating the power of one pulse travelling along two locations A and B of a faulty heating cable;

Figure 5 shows a diagram illustrating the powers of two opposite
 10 pulses travelling along a faulty cable from locations A to B and from locations B to A respectively and meeting in a meeting location C in between locations A and B;

Figure 6, 6a shows a system for determining one or more cable fault locations or areas in an electric heating cable.

15

Detailed description of exemplary embodiments

Figure 1 shows a diagram illustrating one pulse travelling through a (faultless) heating cable from one cable location (or cable end) A and launched at a moment T_A to another one B, where it arrives at a moment T'_1 . The period
 20 between T_A and T'_1 is equal to the electrical transit time t_{AB} between A and B. The value of the power of the pulse at location A is P_A , which power decreases –due to the cable's loss, substantially caused by the resistor material between the cable's well conductive feeding lines– to a value P_A' on arrival at location B.

Figure 2 shows a diagram illustrating two opposite pulses travelling
 25 from A to B (indicated as white pulse) and, oppositely, from B to A ((indicated as black pulse) respectively and meeting in a meeting location C in the middle between A and B. As both pulses are sent at the same moment T_A from the opposite cable ends, they will meet in the middle of the cable section and fortify each other such that the power dissipation in that meeting point C will
 30 rise fourfold, viz. because both voltages, $U_{C(A)}$ (i.e. the voltage in C caused by

the pulse launched in A) and $U_{C(B)}$ (i.e. the voltage in C caused by the pulse launched in B) will be added one another, causing that $U_C = U_{C(A)} + U_{C(B)} = 2 * U_{C(A)} (= 2 * U_{C(B)})$ and thus $P_C = (2 * U_{C(A)})^2 / R_C = 4 * U_{C(A)}^2 / R_X = 4 * P_{C(A)}$. As this power is dissipated by two pulses (viz. the first pulse and the opposite pulse), at the meeting location C the power dissipation per pulse is twice compared with the power dissipation at all other locations of the cable. As is illustrated in figure 2, the meeting (or crossing) of both pulses in point C, causing extra power dissipation there, will cause, after an initial power doubling, a power fall, which results in a dip in course of the power of the pulse, travelling further from point C towards its end point B, which dip can be detected at the other side B of the cable, viz. by comparing the power P_A'' (i.e. the remaining power of the pulse sent from location A) measured at location B (at moment T'_1 , i.e. the pulse launching moment T_A plus the transit time t_{AB} of an electrical pulse from A to B), with the power P_A' (indicated as a dashed line) measured without an (opposite) electric pulse transmitted from location B towards location A (and thus without causing voltage doubling at any meeting point between A and B).

So, when C is a location in which the heating cable functions faultless (i.e. the resistor material is well connected to the feeding lines), a relative power dip of the pulse sent from location A can be detected at location B, which power dip can be measured by measuring the power (P_A') of the remaining pulse at location B and comparing it with a previously or afterwards determined level (P_A').

Figure 3 is similar to figure 2 but differs from it by the location C which is to be investigated by sending pulses from both sides –i.e. the locations A and B– to it. Figure 3 illustrates that when the distance A – C (location C is determined by the mutual difference in the pulse launching moments T_A and T_B) is larger than C – B the starting power P_A of the pulse which is launched from location A, needs to be larger than the starting power P_B of the pulse which is launched from location B, as it will be preferred that both mutually

opposite pulses have about the same power value during their meeting/crossing moment C. For the rest the effects, illustrated in figure 3 are equal to those shown in figure 2. In figure 3 the complete course of the pulse sent from B to A has been drawn: it can be seen that the powers of both pulses
5 will be affected by their mutual crossing in meeting location C, causing that their respective pulse voltages are added to (about) the double voltage, causing a fourfold power dissipation, which, however, is assigned to both pulses: each pulse thus experiences about a twofold power dissipation during the pulse crossing, as a result of which the power course of both pulses will be experience
10 a dip, which can be seen in figure 3.

Figures 4 and 5 illustrate the effect of a faulty cable area between locations D and E on pulses sent from the locations A and B respectively.

In figure 4 a pulse is sent from location A to location B, travelling along faultless areas A – D and E – B, as well as along the faulty cable area D
15 – E. Due to the resistance between the feeding lines caused by the resistor material connected to both feeding lines, the pulse power will start with value P_A and will decrease regularly until location D. As the cable area between locations D and E are faulty, i.e. the resistance material is disconnected there from one or both feeding lines, no electric current will flow through the resistor
20 material in that area D – E when the (feeding) pulse travels along that area D – E and thus no power (power) dissipation will occur there. For that reason the pulse power will not (or hardly) decrease: the power course will be rather constant instead of decreasing as is the case when the cable area D – E would be faultless (see e.g. figure 1). Due to this effect the remaining power P_A' at
25 location B will be higher now than when the area D – E would have been faultless (compare the level of P_A' here with the level of P_A' in figure 1).

Figure 5 illustrates sending of one pulse from A to B and another pulse, oppositely, from B to A; both pulses are launched at about the same moment T_1 , causing the both pulses will meet one another ("cross") about in
30 the middle between A and B, at meeting location C. If, as was the case in the

example illustrated in figure 2, the cable would be faultless at location D, extra power dissipation would occur there due to doubling of the pulse voltage and thus doubling of the power dissipation of each individual pulse, resulting in lower values for P_A'' and P_B'' (which would have been P_A' and P_B' without the "pulse crossing effect"). However, as in this example, illustrated in figure 5, location C is inside the faulty area D – E, despite the doubling of the pulse voltage in meeting location C, as there is no power dissipation at all (due to the disconnection of the resistor material from its feeding lines), there will also be no extra power dissipation at location C and for that reason no power dip (as seen in e.g. figure 2) will occur at all. So the remaining power P_A'' will have the same level as the power P_A' shown in figure 4.

In this way it can be detected whether the location C is faulty or faultless. It may be clearly understood that the location C of the meeting point of the mutual opposite pulses can be varied by varying the moments T_A and T_B at which the opposite pulses are "launched" at the cable ends A and B towards their opposite ends B and A respectively, or rather by varying the time difference between T_A and T_B (i.e. their period p_{1-2}) within the electrical transit time t_{AB} for a pulse to travel from A to B or *vice versa*. So, by varying p_{1-2} from $-t_{AB}$ to $+t_{AB}$ the location C of the meeting point of the oppositely travelling pulses can be set and, by doing so, all locations C between A and B can be checked for a fault in the connection of the resistor material with the feeding lines.

In each of such measurement of the local cable condition, at subsequently varying pulse meeting locations C, it may thus either be concluded that, if the power P_A'' is lower than the power P_A' , the investigated location C is not faulty, or reversely, it may be concluded that that if the power P_A'' is equal or even (see figures 4 and 5) higher than the power P_A' , location C is faulty.

By e.g. plotting or any other graphical display of the results for the varying locations C from location A to location B, a reliable image can be made

of the condition of the complete cable section A-B, which enables to determine the fault locations or areas of the heating cable attached to the relevant e.g. pipe section to be heated, after which only the pipe isolation layer needs to be removed in order to replace the faulty heating cable part by a new, faultless cable part, thus preventing to be forced to remove the pipe isolation over a considerably larger area.

Depending on the location of meeting C, i.e. more towards location B or more towards location A, it may be preferred either to launch, in steps a. and b. a signal from A to B and (in step b.) an opposite signal from B to A (as illustrated in the figures), or to launch, in steps a. and b. a signal from B to A and (in step b.) an opposite signal from A to B (not illustrated in the figures):

I. If the signal meeting point C is located more towards location B (e.g. in figure 3) it may be preferred to compare the values of P_A' and P_A'' , both originated by a signal P_A launched in A, which signal P_A preferably will be chosen larger than P_B in order to achieve signal magnitudes $P_{C(A)}$ and $P_{C(B)}$ in meeting point C which are about equal, due to which also the values of P_A' (step a.) and P_A'' (step b.) will be rather large and thus better detectable. In that case the process steps are ($X = A$, $Y = B$, $Z = C$):

a. sending an electrical signal having a predetermined electric power P_A , from a location A to a location B of the cable and determining the power P_A' of the signal arrived at location B;

b. sending an electrical signal having said predetermined electric power P_A , from location A at a moment T_A , as well as sending an opposite electrical signal having a predetermined electric power P_B from location B at a moment T_B which is chosen such that the first signal and the opposite signal meet each other at a predetermined location C between the locations A and B, and determining the power P_A'' of the signal arrived at location B;

c. comparing the power P_A'' of the signal arrived at location B determined in step b. with the power P_A' of the signal arrived at location B determined in step a. and concluding either that

- if the power P_A'' determined in step b. is lower than
5 the power P_A' determined in step a., location C is not faulty, or
- if the power P_A'' determined in step b. is not lower
than the power P_A' , location C is faulty.

II. If, however, the signal meeting point C is located more
towards location A it may be preferred to compare the values of P_B' and P_B'' ,
10 both originated by a signal P_B launched in B, which signal P_B preferably
will be chosen larger than P_A in order to achieve signal magnitudes $P_{C(A)}$
and $P_{C(B)}$ in meeting point C which are about equal, due to which also the
values of P_B' (step a.) and P_B'' (step b.) will be rather large and thus better
detectable. In that case the process steps are ($X = B$, $Y = A$, $Z = C$):

15 a. sending an electrical signal having a predetermined electric
power P_B , from a location B to a location A of the cable and determining
the power P_B' of the signal arrived at location A;

b. sending an electrical signal having said predetermined
electric power P_B , from location B at a moment T_B , as well as sending an
20 opposite electrical signal having a predetermined electric power P_A from
location A at a moment T_A which is chosen such that the first signal and
the opposite signal meet each other at a predetermined location C
between the locations B and A, and determining the power P_B'' of the
signal arrived at location A;

25 c. comparing the power P_B'' of the signal arrived at location A
determined in step b. with the power P_B' of the signal arrived at location
A determined in step a. and concluding either that

- if the power P_B'' determined in step b. is lower than
the power P_B' determined in step a., location C is not faulty, or

– if the power P_B'' determined in step b. is not lower than the power P_B' , location C is faulty.

Figure 6 shows a system for determining one or more cable fault locations or areas in an electric heating cable. The heating cable comprises conductors 100a,b and heating material 102 electrically connected between conductor lines 100a,b. Most of the length of the heating cable has been left out. The system comprises a first controller 110, a second controller 112, a first pulse signal generator 114, a detector 116 and a second pulse generator 118. First and second pulse generator 114, 116 have outputs coupled to the conductor lines 100a,b on mutually opposite ends of the cable. Detector 118 has an input coupled to the conductor lines 100a,b on the same side of the cable as second pulse generator 114, 116. First controller 110 has an output coupled to a control input of second pulse generator 116 and an input coupled to an output of detector 118. Second controller 112 has an output coupled to a control input of first pulse generator 116. First and second controller 110, 112 are in communication with each other.

In operation first controller 110 initiates measurement cycles by transmitting control signals to second controller 112 to trigger first pulse generator 116 to transmit pulse signals along the heating cable. The timing of transmission may be controlled by timing of the control signals, or by reference to a common clock or clock circuits in first and second controller 110, 112 (the latter may be synchronized by detecting clock time at one clock at arrival of a pulse transmitted through the heater cable after transmission at a known clock value at the other clock). Detector 118 measures power of arriving pulses and supplies the measurement results to first controller 110. In part of the measurement cycles first controller 110 applies control signals to second pulse generator 116 to transmit pulse signals over the heating cable in a selected time relation to transmitted pulses from first pulse generator 114, transmitted in response to control signals to second controller 112. First controller 110 may supply information about the travel distance to the intended crossing point of

the pulses (or equivalently, about the timing relation between the pulses) to second controller 112.

First and second pulse generator may be configured to adapt the pulse signal shape and power dependent on the selected time relation on this
5 information so as to generate signals that optimally approximate a pulse shape and/or signals of predetermined power levels at the intended crossing point of the signals in the heating cable. Alternatively, the information may take the form of power level and/or shape control values.

A table of respective predetermined signal shapes for use for
10 different distances to the crossing point of the pulses may be used to control signal shaping at the pulse generators. Methods of selecting pulse shapes are known per se. For example, in a linear approximation, the signal at any point in the heating cable can be represented as a superposition of components at different frequencies. Known signal attenuation and travelling speed in the
15 cable for the different frequency components make it possible to predict the phase and amplitude relation between the different frequency components at any position, given their phase and amplitude relation at an input of the heating cable. In an embodiment predetermined amplitude and phase relations between the frequency components of a pulse signal may be used, which are
20 known per se, and amplitude and phase relations at the cable input may be selected that, given the known travel time and attenuation to a selected crossing point result in the predetermined amplitude and phase relations of the pulse signal at the crossing point. From this an input signal shape may be determined and the pulse signal generators may be controlled to generate
25 pulses of these shape. In another embodiment, an optimization algorithm may be used to search for an adapted the input signal shape that minimizes a deviation of a predicted signal at the crossing point from a pulse shape and the selected signal may be transmitted. A linear prediction may be used, as described in the preceding, or any other model, including non-linear models.

In a further embodiment, as shown in fig 6a, detectors may be provided on both sides of the heating cable. This makes it possible to perform measurements wherein the roles of the two sides are interchanged. The provides for more reliable measurements, for example by measuring received
5 power on the side closest to the crossing point.

Claims

1. A method of determining a cable fault location or area in an electric heating cable comprising at least two conductor lines and an electrical resistor material in between the conductor lines and electrically connected to said conductor lines in order to dissipate power over mainly the whole
5 length of the cable when connected to an electric power source, said cable fault including or caused by electrical disconnection between the resistor material and at least one of said conductor lines in said one or more fault locations or areas, resulting in an interruption of the power dissipation in said locations or areas, the method comprising the following steps, steps a.
10 and b. in any order:
 - a. sending a first electrical pulse signal having a predetermined electric power P_X , from a location X (A or B) to a location Y (B or A respectively) of the cable and determining the power $P_{X'}$ of the signal arrived at location Y;
 - 15 b. sending a second electrical pulse signal having said predetermined electric power P_X , from location X at a moment T_X , as well as sending a further electrical pulse signal having a predetermined electric power P_Y in an opposite direction from location Y at a moment T_Y which is chosen such that the first signal and the signal in the opposite direction meet
20 each other at a predetermined location Z between the locations X and Y, and determining the power $P_{X''}$ of the signal arrived at location Y;
 - c. comparing the power $P_{X''}$ of the signal arrived at location Y determined in step b. with the power $P_{X'}$ of the signal arrived at location Y determined in step a. and concluding either that
25 – if the power $P_{X''}$ determined in step b. is lower than the power $P_{X'}$ determined in step a., location Z is not faulty, or

- if the power P_X'' determined in step b. is not lower than the power P_X' , location Z is faulty.
- 2. Method according to claim 1, where the electrical transit time t_{XY} for either
5 electrical pulse signal to travel from X to Y or *vice versa* and where said steps are repeated using different values for the period $p_{X,Y}$ between T_X and T_Y ranging from $-t_{XY}$ to $+t_{XY}$.
- 3. Method according to claim 2, where for the relevant values of said period
10 $p_{X,Y}$ and the resulting values of the meeting location Z it is registered for which values of Z location Z is faulty and for which values of Z location Z is not faulty.
- 4. Method according to any preceding claim, where the powers P_X and P_Y are
15 adapted dependent on distances to the location Z so that a first ratio between the transmitted power P_X and P_Y is adapted dependent on the distances, and a second ratio of power levels of the signals at the location Z due to of the signals transmitted in opposite directions is changed in the direction of a ratio of one, compared to a value of the second ratio if equal
20 power levels would be used for the signals transmitted in opposite directions.
- 5. Method according to claim 4, where the powers P_X and P_Y are chosen so that the power $P_{Z(X)}$ at location Z caused by the signal sent from location X
25 and the power $P_{Z(Y)}$ at location Z caused by the signal sent from location Y have substantially equal values.
- 6. Method according to claim 4 or 5, wherein, when the meeting location Z
30 (C) is closer to location Y (B, A) than to location X (A, B), the power P_X of the signal sent from location X both in step a. and in step b. is chosen

larger than the power P_Y of the signal sent from location Y in step b., and wherein the power P_X'' of the signal arrived at location Y determined in step b. is compared with the power P_X' of the signal arrived at location Y determined in step a.

5

7. Method according to claim 4, 5 or 6, wherein, when the meeting location Z (C) is closer to location X (A, B) than to location Y (B, A), the power P_Y of the signal sent from location Y both in step a. and in step b. is chosen larger than the power P_X of the signal sent from location X in step b., and wherein the power P_Y'' of the signal arrived at location X determined in step b. is compared with the power P_Y' of the signal arrived at location X determined in step a.

10

8. Method according to any preceding claim, where signal shapes of the signals sent from locations X and Y respectively are adapted dependent on distances to the meeting location Z.

15

9. Method according to claim 1, where the measurement uncertainty is improved by successively repeating said steps a. to c.

20

10. Method according to any one of the preceding claims, wherein the roles of the locations X and Y are interchanged, dependent on the location Z, the conclusion that location Z is faulty or not being determined from power determined at location X for locations Z in a first range and from power determined at location Y for a second range of locations Z.

25

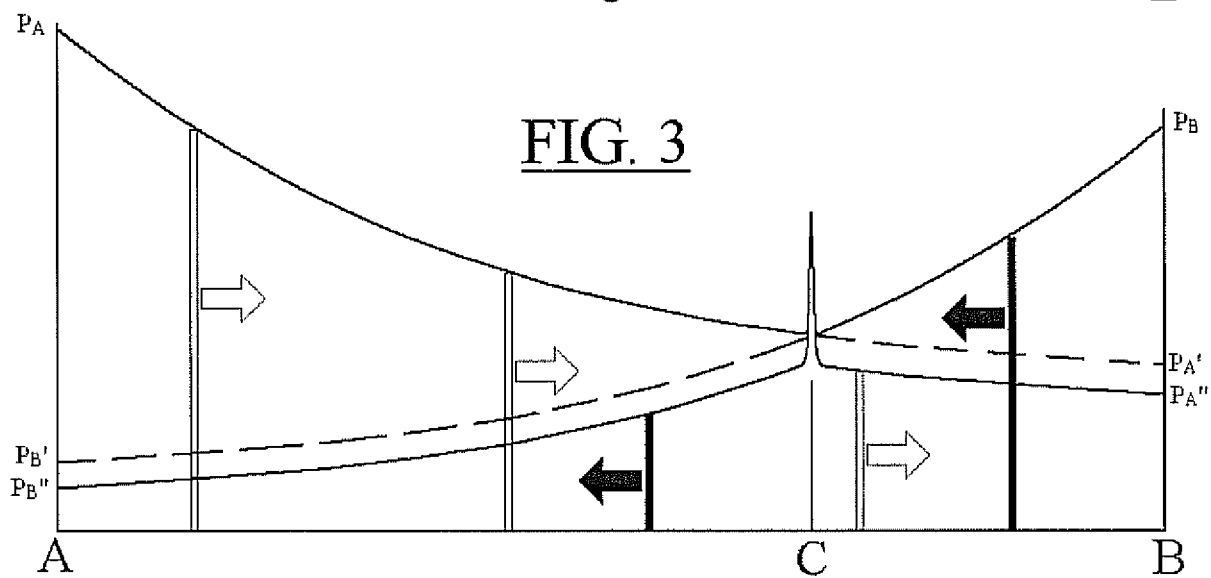
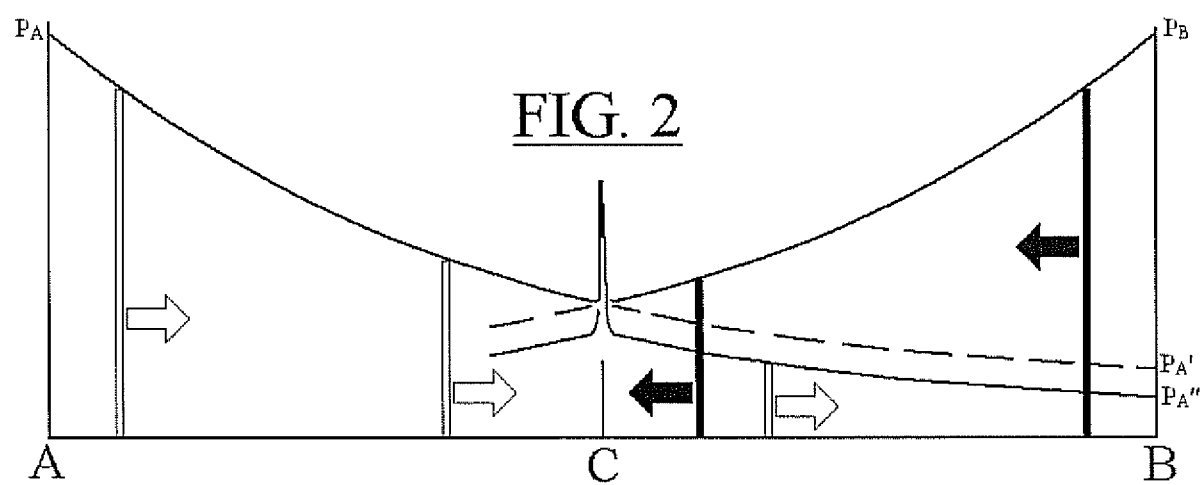
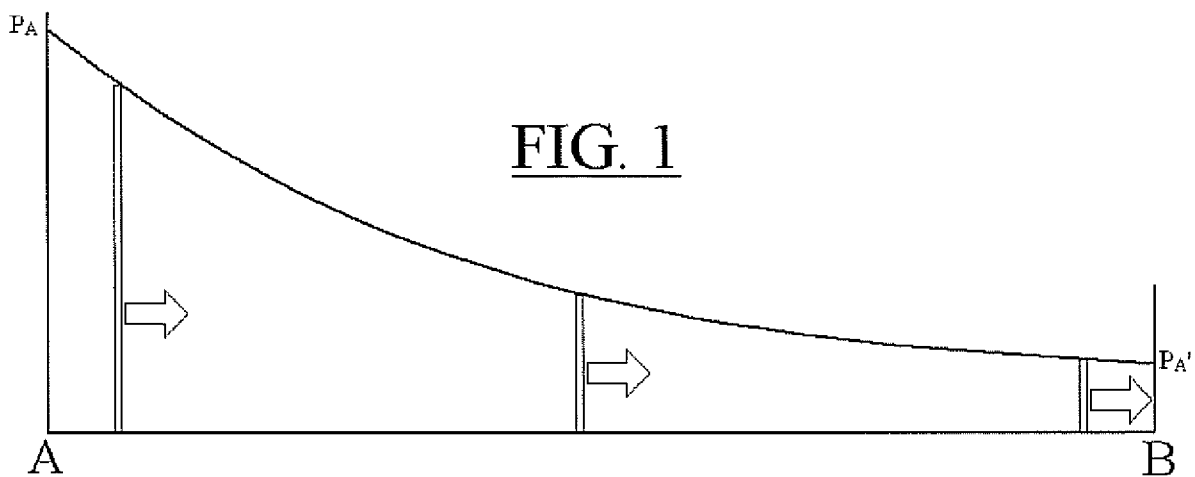
11. A method of determining a cable fault location or area in an electric heating cable, the method comprising the following steps:
- sending an electrical pulse signal having a predetermined electric power P_X , from a location X at a first end of the hearing cable at a moment T_X ,

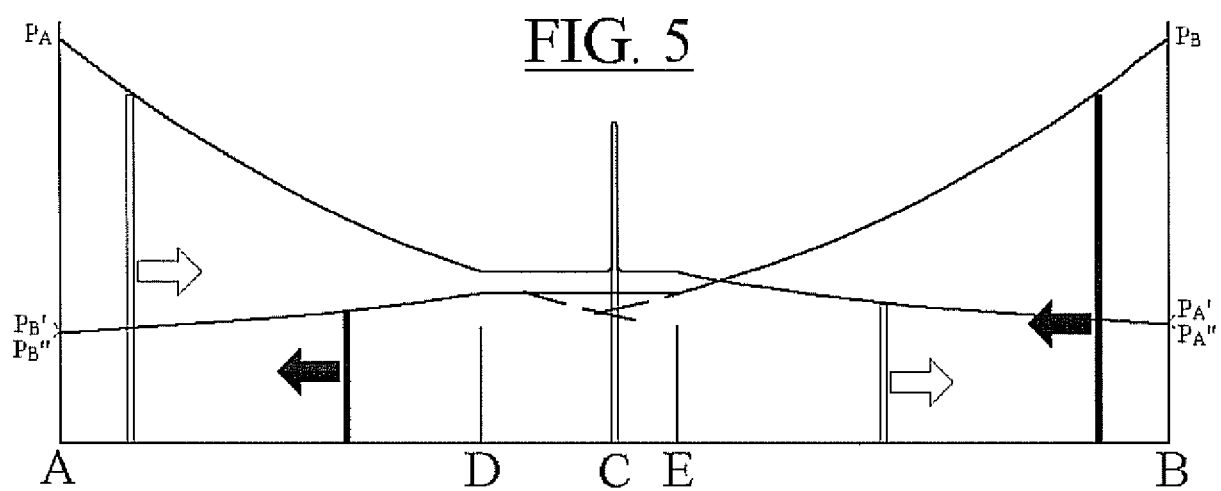
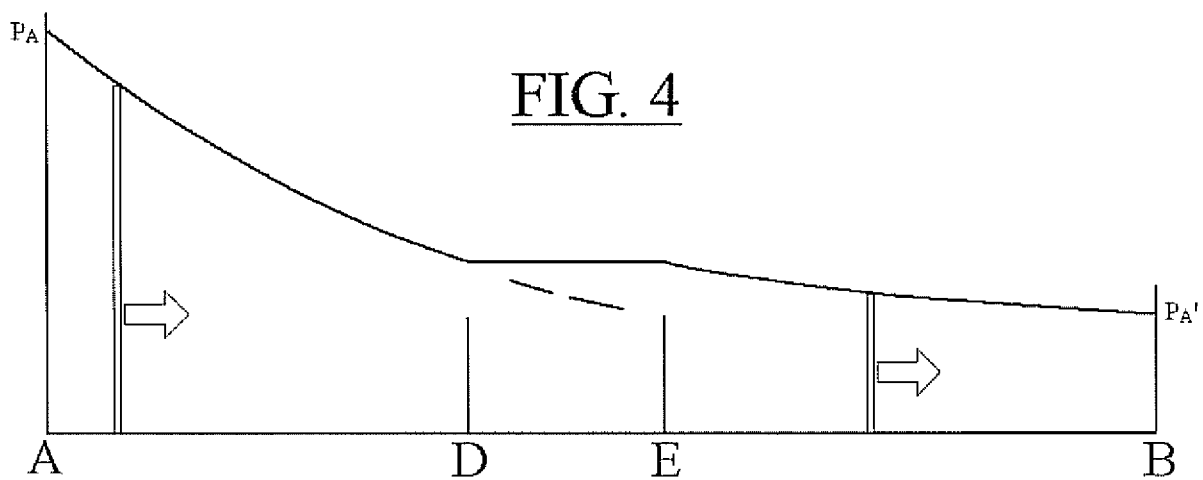
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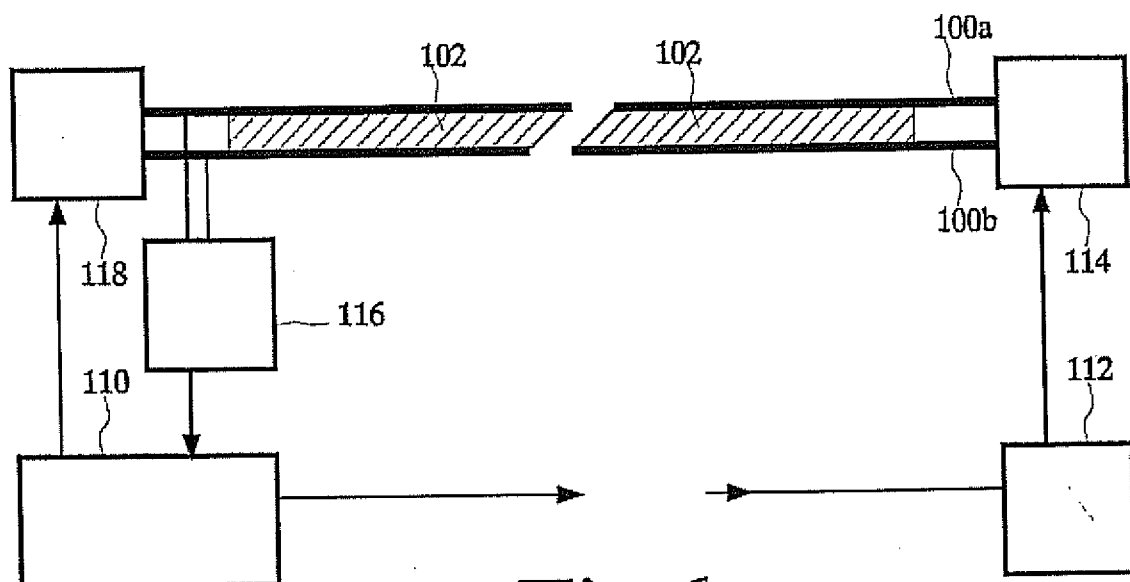
sending a further electrical pulse signal having a predetermined electric power P_Y in an opposite direction from a location Y a second end of the heating cable at a moment T_Y ,

- measuring a received power P_X'' of the signal received at location Y;
 - 5 - comparing the measured P_X'' of the received signal at location Y with a reference power P_X' and concluding either that
 - if the measured power P_X'' is lower than the reference power P_X' , that the cable at location Z is not faulty, or
 - if the measured power P_X'' is not lower than the power P_X' , that the
- 10 cable at location Z is faulty.

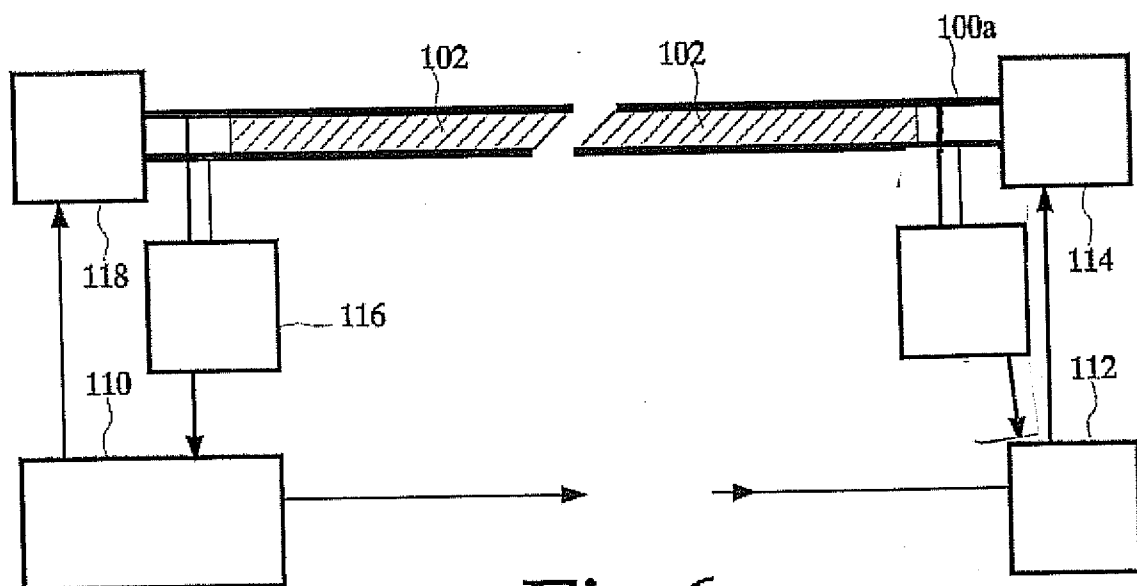
12. System for determining a cable fault location or area in an electric heating cable comprising at least two conductor lines having an electrical resistor material in between them and electrically connected to said conductor lines
- 15 in order to dissipate power over mainly the whole length of the cable when connected to an electric power source, said cable fault including or caused by electrical disconnection between the resistor material and at least one of said conductor lines in said one or more fault locations or areas, resulting in an interruption of the power dissipation in said locations or areas, the
- 20 system being arranged for performing the method according to any preceding claim.







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INTERNATIONAL SEARCH REPORT

International application No
PCT/NL2010/050200

A. CLASSIFICATION OF SUBJECT MATTER

INV. G01R31/08

ADD. H05B3/56

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)

G01R H05B

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

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

EP0-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 270 661 A (BURNETT GALE D [US]) 14 December 1993 (1993-12-14) column 6, line 51 - column 8, line 15; figure 14 column 15, line 25 - column 16, line 9	1-3,9, 11,12
A	EP 1 679 521 A (UTILX CORP [US]) 12 July 2006 (2006-07-12) paragraphs [0003], [0016], [0027], [0028]; figures 8,9	1,11,12
A	GB 1 275 374 A (VNII ELEKTROENER GETIKI [RU]) 24 May 1972 (1972-05-24) the whole document	1-12
A	EP 0 399 583 A (BURNETT GALE D [US]) 28 November 1990 (1990-11-28) the whole document	1-12
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Further documents are listed in the continuation of Box C.



See patent family annex.

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"&" document member of the same patent family

Date of the actual completion of the international search

14 June 2010

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21/06/2010

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INTERNATIONAL SEARCH REPORT

International application No
PCT/NL2010/050200

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 719 503 A (BURNETT GALE D [US]) 17 February 1998 (1998-02-17) figure 6 column 10, line 18 - line 21 -----	11

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/NL2010/050200

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EP 0399583	A	28-11-1990	CA 2015544 A1 DE 69025428 D1 DE 69025428 T2 US 4970467 A	27-10-1990 28-03-1996 13-06-1996 13-11-1990
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