

(19) World Intellectual Property Organization
International Bureau



(43) International Publication Date
25 January 2007 (25.01.2007)

PCT

(10) International Publication Number
WO 2007/011196 A1

(51) International Patent Classification:

G01R 31/08 (2006.01)

(21) International Application Number:

PCT/LT2006/000006

(22) International Filing Date: 18 July 2006 (18.07.2006)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:

2005 067 20 July 2005 (20.07.2005) LT

(71) Applicant (for all designated States except US): UAB "ENERGIJOS SRAUTAS" [LT/LT]; Savanoriu pr. 65A, 03149 Vilnius (LT).

(72) Inventors; and

(75) Inventors/Applicants (for US only): MARKEVICIUS, Andronis Linas [LT/LT]; Smetonos al. 43-9, 45323 Kaunas (LT). GUDZIUS, Saulius [LT/LT]; Griunvaldo g. 4-60, 44330 Kaunas (LT). MORKVENAS, Alfonsas [LT/LT]; Topoliu g. 2-1, 51370 Kaunas (LT). MARKEVICIUS, Linas [LT/LT]; Kriviu g. 35-13, 01209 Vilnius (LT).

(74) Agent: ZABOLIENE, Reda; METIDA Law firm of Reda Zaboliene, Gedimino pr. 45-6, 01109 Vilnius (LT).

(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LV, LY, MA, MD, MG, MK, MN, MW, MX, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, LV, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

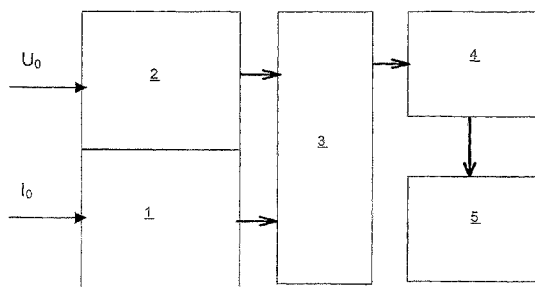
- with international search report
- before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: A METHOD OF EARTH FAULT IDENTIFICATION AND LOCATION IN THREE-PHASE ELECTRICAL NETWORK

$$f_2 = \sum_{k=1}^L |rem(\tilde{r}_k, \tilde{S}_k) - rem(\tilde{r}_k, S_k)| = \min$$

(I)



(57) Abstract: The invention relates to the area of electrical power network and may be applied to a method of permanent or short-term earth fault identification in a three-phase electrical distribution network and distance determination to the fault place. Better accuracy for the earth fault place location is achieved by performing registrations not longer than 100 μs and with time intervals smaller than 100 ns, thus decreasing the influence of noises of lower than 10 kHz frequency. The distance between the beginning of the feeder's section and earth fault place is defined by minimising the goal function f_2 , which is the function of the difference of registered and simulated processes: (I).

WO 2007/011196 A1

A METHOD OF EARTH FAULT IDENTIFICATION AND LOCATION IN THREE-PHASE ELECTRICAL NETWORK

The invention is intended for the area of electrical power network and may be applied to a method of the earth fault place location and identification in a three-phase electrical distribution network.

The main faults of electrical distribution networks are wire breaks and/or earth faults. Fault detection methods in electrical distribution networks are described in patents SU 1762279 and SU 1698849. Fault place location in patent SU 1762279 is based on useful reflection from the place of fault of signal identification and its usage for the fault location. A method of phase earth fault location is described in patent SU 1698848, where the first half-wave of the discharge current is fixed in a place of short circuit, two-component amplitudes of the discharge current of a half-wave spectrum are measured and under a respective formula distance to the earth fault place is founded.

. The shortcoming of both inventions is significantly complicated and not very precise earth fault location. In addition, none of the inventions fix short-term earth faults.

The invention presents a new method of earth fault location in a three-phase electrical network. It differs from the well-known methods by registration not only permanent but also short-term self-disappearing earth faults and more precise location of former or present earth faults between the phase and the earthed object in one section of a three-phase feeder substation connected to the bus section of the feeder substation. It permits the supervisory services of the electrical network to efficiently eliminate the occurred earth fault and/or to prevent possible faults, where for some reasons (the spark, touch of the tree branches, etc.) short-term earth faults occur.

A method is characterised by its registration of the initial processes of zero-phase sequence and voltage variations after earth fault, which are registered at the voltage transformer connected to the bus section and in the feeder current transformer of a zero-phase sequence current. The better accuracy of the earth fault place location is achieved by not longer than 100 μ s performance and smaller than 100 ns time intervals, decreasing by this noise influence, which frequency is lower than 10 kHz, by special algebra separating the processes running in other feeders and loading them into a model, where the simulated process is compared with the registered one. The place of earth fault and

model element parameters are found by minimising goal function which is the function of the difference between the registered and simulated processes.

This invention will be described more thoroughly with reference to the enclosed drawings, where:

Fig. 1 presents a block-diagramme of the operational device for this method realisation;

Fig. 2 presents a scaling filter scheme of a high frequency current process.

For the earth fault place location this invention uses a device schematically described in table 1, consisting of a zero-phase sequence current process identification and separation of analogue link block 1, identification of a zero-phase sequence voltage process and separation of analogue link block 2, transducers of analogue code and memory block 3, converting measured within earth fault analogue zero sequence current and voltage processes into a buffer memory, controllers block 4, co-ordinating identification of the registered process performing its analysis, modelling, parameters optimisation, fault identification and being in connection with the outer systems, interface and indication block 5 demonstrating the estimated distance to the place of earth fault

Under this invention earth fault between a phase and the earthed object in one three-phase feeder connected to the feeder substation bus section is located by registering in an analogue method after earth fault zero-phase sequence initial current I_0 and voltage U_0 variations processes in due blocks 1 and 2 obtained from a voltage transformer connected to a bus section and from the feeder's zero-phase sequence high frequency current scaling filter 6 (Fig. 2) equipped in block 1. Parameters of a high frequency current process scaling filter 6 depend on the feeder's section and configuration. Use of scaling filter 6 permits registering initial processes after earth fault of a zero-phase sequence high frequency current and locating faults more precisely. Also better accuracy of earth fault location due this invention is achieved by registering faults no longer than 100 μ s and in smaller than 100 ns time intervals reducing by this noise influence whose frequency is smaller than 10 kHz. Registered analogue signal block 3 converts into a digital one. In Unit 4 by special algebra processes operating in other feeders are defined and loaded into a model where the simulated process is compared with the registered one. The place of earth fault and model element parameters, i.e. the simulated voltage and current transient characteristics in a model as well as the feeder's wave parameters and

node capacity are found by minimising goal function, which is the function of the difference between the registered and simulated process.

The method of this invention is composed of an algorithm, the processor of which is available in controller block 4, locates earth fault in the feeders' sections in the following stages.

1) At the first stage it is checked whether earth fault occurred in the device feeder. Earth fault is supposed to occur in the device feeder if number (I) has a positive sign:

$$p = \sum_{j=1}^{n_1} i_j u_j \quad (\text{I})$$

Where i_j – current j registration; u_j – voltage value j registration; n_1 – number of part of current values of all N registrations: $n_1 < N$.

2) If the first stage confirms earth fault occurrence in the feeder, i.e. if number (I) is positive – it fulfils the second stage, during which by minimising goal function f_1 the parameters of transitional characteristics of current and voltage measuring transformers are defined.:

$$f_1 = \sum_{j=1}^{n_2} |rem(F_1, derem(1 - derem(I_1, U_1), 1 + derem(I_1, U_1)))| = \min \quad (\text{II})$$

Where I_1 – vector: $I_1 = [i_1, i_2, \dots, i_{n_2}]$, U_1 – vector: $U_1 = [u_1, u_2, \dots, u_{n_2}]$, F_1 – n_2 value vector of a definite form impulse function ($n_2 < N$), $1 = [1, 1, \dots, 1]_{n_2}$; rem and $derem$ – algebra operations for equal clearance vectors characterised by following formulas:

$$(z_k)_n = rem((x_k)_n, (y_k)_n) \quad (\text{III})$$

$$z_k = \sum_{j=1}^n x_j (y_{k+1-j} - dy_{k+1-j}); (dy_k)_n = [0, y_1, y_2, \dots, y_{n-1}]; \quad (\text{IV})$$

$$(x_k)_n = derem((z_k)_n, (y_k)_n) \quad (\text{V})$$

3) The third stage by minimising goal function f_2 determines the feeder's section where earth fault occurred and distance in meters from the beginning of the section to the earth fault place:

$$f_2 = \sum_{k=1}^L |rem(F_2, \tilde{S}_k) - rem(F_2, S_k)| = \min \quad (\text{VI})$$

Where $\mathbf{F}_2 - M$ values vector of a definite form impulse function ($N = LM$, $L \geq 1$), L – positive integer, $\mathbf{S}$ and $\tilde{\mathbf{S}}$ – vectors obtained from registrations and found in a model are calculated using the following formulas:

$$\hat{\mathbf{S}}_k = \frac{(\hat{s}_{M(k-1)+j})_M}{a_k}; \quad a_k \in \left\{ \left| \hat{s}_{M(k-1)+1} \right|, \left| \hat{s}_{M(k-1)+2} \right|, \dots, \left| \hat{s}_{M(k-1)+M} \right| \right\} \quad (\text{VII})$$

$$\hat{s}_{M(k-1)+j} = \hat{u}_{M(k-1)+j} - w \hat{i}_{M(k-1)+j} \quad (\text{VIII})$$

Where $\hat{u}$ and $\hat{i}$ – voltage and current values obtained in registrations and calculated in a model; w – non-negative rational number. Derivative results are described in indication block 5 where except distance from the beginning of the section to the earth fault place, section number and identification reliability where earth fault occurred are also indicated.

CLAIMS

1. Earth fault detection method between the phase and earthed object place isolated from the earth in one section of a three-phase feeder by a device consisting of a zero-phase sequence current process identification and separation of analogue link block (1), zero-phase sequence voltage process identification and separation of analogue link block (2), analogue code converter block (3), controllers block (4), interface and indication block (5), characterised by:

- registering in blocks (1) and (2) after earth fault initial zero-phase sequence current I_0 and voltage U_0 transient processes obtained from the voltage transformer connected to the bus section and feeder's scaling filter (6) of a zero-phase sequence high frequency current arranged in block (1);
- checking if earth fault occurred in the feeder, the occurrence of which shows a positive number (1) sign:

$$p = \sum_{j=1}^{n1} i_j u_j \quad (\text{I}),$$

where i_j – current j registration ; u_j – voltage value j registration; $n1$ – number of the part of currency values of all N registrations: $n1 < N$;

- in case the number (I) is positive – determining the parameters of transitional characteristics of current and voltage measuring transformers by minimising goal function f_1 :

$$f_1 = \sum_{j=1}^{n2} | \text{rem}(\mathbf{F}_1, \text{derem}(\mathbf{1} - \text{derem}(\mathbf{I}_1, \mathbf{U}_1), \mathbf{1} + \text{derem}(\mathbf{I}_1, \mathbf{U}_1))) | = \min \quad (\text{II})$$

where $\mathbf{I}_1$ – vector: $\mathbf{I}_1 = [i_1, i_2, \dots, i_{n2}]$, $\mathbf{U}_1$ – vector: $\mathbf{U}_1 = [u_1, u_2, \dots, u_{n2}]$, $\mathbf{F}_1$ – $n2$ values vector of a definite form impulse function ($n2 < N$); $\mathbf{1} = [1, 1, \dots, 1]_{n2}$; rem and derem – algebra actions for equal clearance vectors are defined by the following formulas:

$$(z_k)_n = \text{rem}((x_k)_n, (y_k)_n) \quad (\text{III})$$

$$z_k = \sum_{j=1}^n x_j (y_{k+1-j} - dy_{k+1-j}); \quad (dy_k)_n = [0, y_1, y_2, \dots, y_{n-1}]; \quad (\text{IV})$$

$$(x_k)_n = \text{derem}((z_k)_n, (y_k)_n); \quad (\text{V});$$

- determining the feeder's section where the earth fault occurred and calculating the distance in meters from the beginning of the feeder's section to the earth fault place by minimising goal function f_2 :

$$f_2 = \sum_{k=1}^L \left| \text{rem}(\mathbf{F}_2, \tilde{\mathbf{S}}_k) - \text{rem}(\mathbf{F}_2, \mathbf{S}_k) \right| = \min \quad (\text{VI})$$

where $\mathbf{F}_2$ – M values vector of a definite form impulse function ($N = LM$, $L \geq 1$), L – positive integer; $\mathbf{S}$ and $\tilde{\mathbf{S}}$ – vectors obtained from registrations and found in a model are calculated using the following formulas:

$$\hat{\mathbf{S}}_k = \frac{(\hat{s}_{M(k-1)+j})_M}{a_k}; \quad a_k \in \left\{ \left| \hat{s}_{M(k-1)+1} \right|, \left| \hat{s}_{M(k-1)+2} \right|, \dots, \left| \hat{s}_{M(k-1)+M} \right| \right\} \quad (\text{VII})$$

$$\hat{s}_{M(k-1)+j} = \hat{u}_{M(k-1)+j} - w \hat{i}_{M(k-1)+j} \quad (\text{VIII})$$

where $\hat{u}$ and $\hat{i}$ – values of voltage and current obtained in registrations or calculated in a model; w – non-negative rational number.

2. The method according to claim 1, characterised by registering of initial earth fault zero-phase sequence current and voltage transient processes no longer than 100 μs and smaller than 100 ns time intervals reducing by this noise influence with the frequency lower than 10 kHz.
3. The method according to any previous claims, characterised by registering of short-term earth faults.
4. The method according to any previous claims, characterised by registering of one industrial frequency half period and longer duration earth faults.

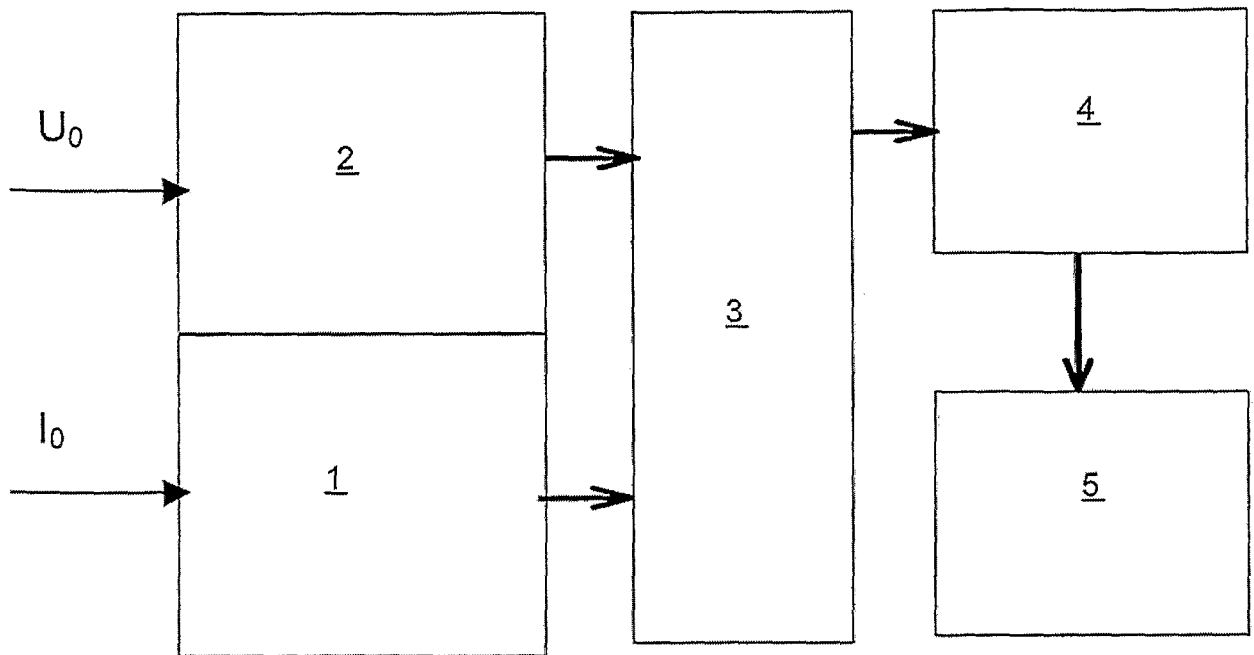


Fig. 1

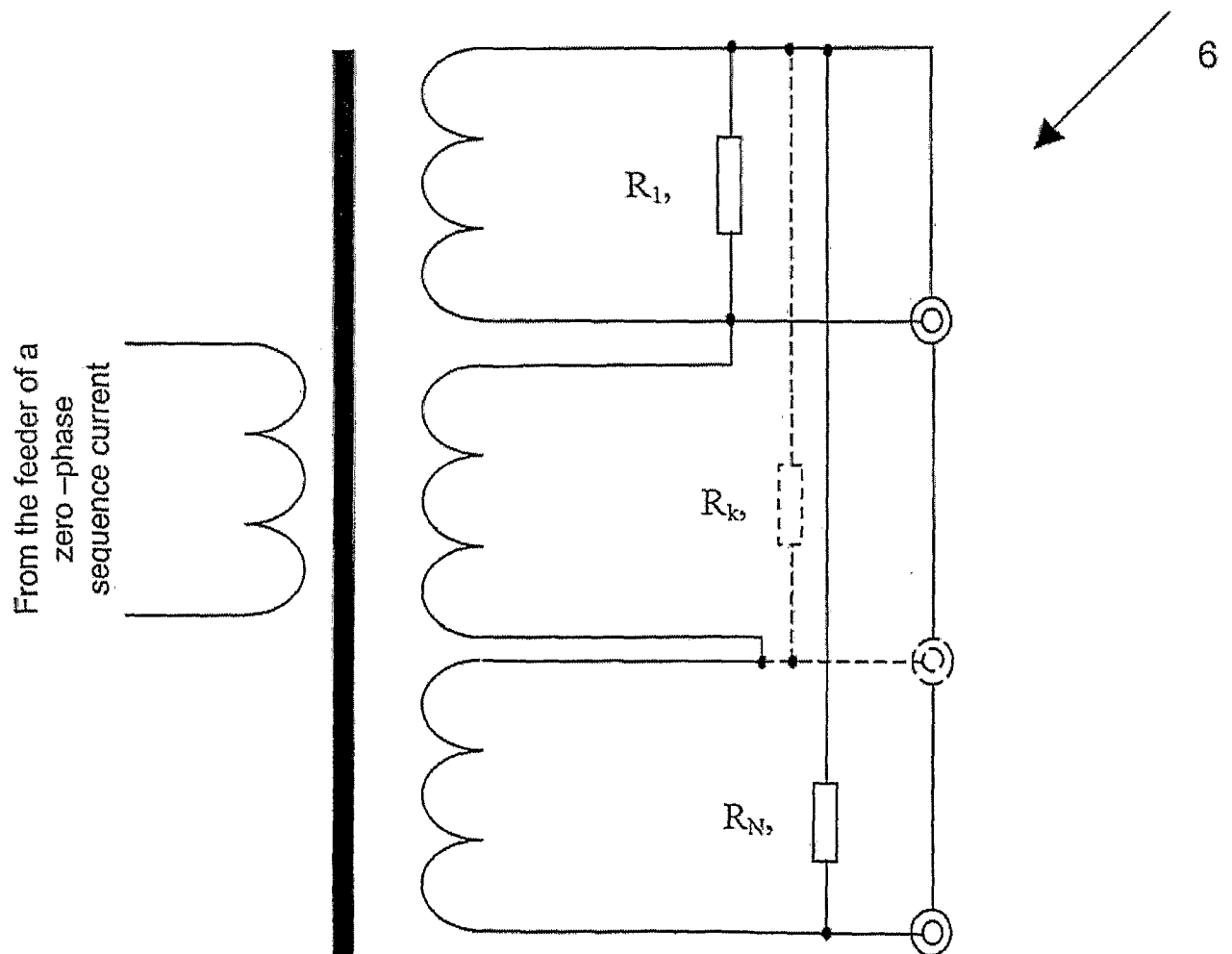


Fig. 2

INTERNATIONAL SEARCH REPORT

International application No
PCT/LT2006/000006

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01R31/08

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

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)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	KEZUNOVIC M ET AL: "A novel method for transmission network fault location using genetic algorithms and sparse field recordings" 2002 IEEE POWER ENGINEERING SOCIETY. SUMMER MEETING. CONFERENCE PROCEEDINGS. CHICAGO, IL, JULY 21 - 25, 2002, IEEE POWER ENGINEERING SOCIETY, NEW YORK, NY : IEEE, US, vol. VOL. 2 OF 3, 21 July 2002 (2002-07-21), pages 1101-1106, XP010610321 ISBN: 0-7803-7518-1 abstract; figures 1,4 page 1101, column 1, paragraph 4 - page 1102, column 1, last paragraph ----- -/-	1-4

☒ Further documents are listed in the continuation of Box C.

☒ 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" earlier 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

29 November 2006

Date of mailing of the international search report

06/12/2006

Name and mailing address of the ISA/
European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,
Fax: (+31-70) 340-3016

Authorized officer

Ernst, Monika

INTERNATIONAL SEARCH REPORT

International application No

PCT/LT2006/000006

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 4 351 011 A (LIBERMAN SALOMON) 21 September 1982 (1982-09-21) abstract; figure 1a column 1, line 50 - column 2, line 2 -----	1
A	SILVEIRA P M ET AL: "An approach using wavelet transform for fault type identification in digital relaying" POWER ENGINEERING SOCIETY SUMMER MEETING, 1999. IEEE EDMONTON, ALTA., CANADA 18-22 JULY 1999, PISCATAWAY, NJ, USA, IEEE, US, vol. 2, 18 July 1999 (1999-07-18), pages 937-942, XP010346434 ISBN: 0-7803-5569-5 abstract page 938, column 2, last paragraph - page 941, column 2, last paragraph -----	1-4
A	NIKANDER A ET AL: "Methods for earth fault identification and distance estimation in a compensated medium voltage distribution network" ENERGY MANAGEMENT AND POWER DELIVERY, 1998. PROCEEDINGS OF EMPD '98. 1998 INTERNATIONAL CONFERENCE ON SINGAPORE 3-5 MARCH 1998, NEW YORK, NY, USA, IEEE, US, vol. 2, 3 March 1998 (1998-03-03), pages 595-600, XP010293689 ISBN: 0-7803-4495-2 page 595, column 1, paragraph 3 - column 2, last paragraph page 597, column 2, paragraph 3 - page 600, column 2, paragraph 1 -----	1-4
A	AMORIM H P ET AL: "Faults location in transmission lines through neural networks" TRANSMISSION AND DISTRIBUTION CONFERENCE AND EXPOSITION: LATIN AMERICA, 2004 IEEE/PES SAO PAULO, BRAZIL 8-11 NOV. 2004, PISCATAWAY, NJ, USA, IEEE, US, 8 November 2004 (2004-11-08), pages 691-695, XP010799946 ISBN: 0-7803-8775-9 page 692, column 2, paragraph 2 - page 695, column 1, paragraph 1 ----- -/--	1

INTERNATIONAL SEARCH REPORT

International application No

PCT/LT2006/000006

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	PEREIRA R A F ET AL: "PMUs optimized allocation using a tabu search algorithm for fault location in electric power distribution system" TRANSMISSION AND DISTRIBUTION CONFERENCE AND EXPOSITION: LATIN AMERICA, 2004 IEEE/PES SAO PAULO, BRAZIL 8-11 NOV. 2004, PISCATAWAY, NJ, USA, IEEE, US, 8 November 2004 (2004-11-08), pages 143-148, XP010799851 ISBN: 0-7803-8775-9 page 143, column 2, paragraph 2 - page 144, column 2, paragraph 1; figure 2 -----	1-4

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/LT2006/000006

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 4351011	A	21-09-1982	CH 640373 A5 30-12-1983
			DE 2911844 A1 18-10-1979
			FR 2422278 A1 02-11-1979
			GB 2020120 A 07-11-1979
			SE 410925 B 12-11-1979
			SE 7803868 A 07-10-1979