EEA fondată în 1950

ELECTROTEHNICĂ, ELECTRONICĂ, AUTOMATICĂ

vol. 66 nr. 2 aprilie-iunie 2018 publicaţie a ICPE ISSN: 1582-5175

Revista EEA este clasificată B+ de CNCSIS şi indexată în bazele internaţionale de date: Elsevier, Scopus, Compendex, ProQuest, EBSCO, Ulrich's, Index Copernicus International

pag. Articole

[Continuare pe coperta 4]

ELECTRA®

www.icpe.ro

EEA fondată în 1950

ELECTROTEHNICĂ, ELECTRONICĂ, AUTOMATICĂ

pag. Articole

Miscellanea Section

* * *

www.icpe.ro

ISSN 1582-5175

Redacţia EEA-Journal

Splaiul Unirii, nr. 313; 030138 Bucureşti, România
Tel. +4021 589 33 00 | Mobil: +40749 070 395
e-mail: eea-journal@icpe.ro
Internet: www.eea-journal.ro

EEA fondată în 1950

ELECTROTEHNICĂ, ELECTRONICĂ, AUTOMATICĂ

vol. 66 nr. 2 aprilie-iunie 2018 publicație a ICPE ISSN: 1582-5175

Revista EEA este clasificată B+ de CNCSIS şi indexată în bazele internaţionale de date:
Elsevier, Scopus, Compendex, ProQuest, EBSCO, Ulrich's, Index Copernicus International

pag. **Articole**

[Continuare pe coperta 4]

EEA

fondată în 1950

ELECTROTEHNICĂ, ELECTRONICĂ, AUTOMATICĂ

pag. Articole

Miscellanea Section

* * *

ICPE
www.icpe.ro

ISSN 1582-5175
9 771582 517002

Redacţia EEA-Journal

Splaiul Unirii, nr. 313; 030138 Bucureşti, România
Tel. +4021 589 33 00 | Mobil: +40749 070 395
e-mail: eea-journal@icpe.ro
Internet: www.eea-journal.ro

EEA fondată în 1950

ELECTROTEHNICĂ, ELECTRONICĂ, AUTOMATICĂ

Publicaţie trimestrială
a ICPE

ISSN 1582-5175

ICPE

"TECHNOLOGIES FOR A **SUSTAINABLE DEVELOPMENT**"

www.icpe.ro

Icpe was founded by the Government Decision no. 868 of 5 August 1950 (under the name „Institutul de cercetări electrotehnice" [Institute of Electrical Research]).

Icpe is a complex structure that covers a wide range of innovative activities connected via the electric profile:

- **R & D** in the national and international programmes of promoting the sustainable development technologies in over 500 research projects.
- **PRODUCTION**: special electric machines, DC & brushless actuators, ecological electric equipment (circuit breakers, contactors, fuses), cables and special electric conductors.
- **SERVICES**:

Metrology (thermal expertise of buildings, thermography (thermal imaging), noise measurement, measurement of electromagnetic disturbances);

Material characterization for determining the electric properties, mechanical properties, thermal properties and the resistance to the environmental factors;

Renewable energy in several systems: photovoltaic, wind, solar-thermal, biomass, biogas, biofuel;

Integrated energy services by energy audit, energy supply;

Consulting services (pre-feasibility studies, feasibility and project studies, evaluation of project proposals, technical projects and implementation, energy management, technical control);

"ELECTRA" Publishing House (founded in 1993) is listed among the publishers recognized by CNCS [National Council of R&D and High Education], starting 2001. So far, 300 technical and beyond books have been published. It is the editor of the journal *EEA*

The Technological Information Centre helps in the innovation implementation in economy and society by the dissemination information of the R&D results, technological documentation and operators training in order to facilitate the capitalization results.

Icpe is a brand on the Romanian market and abroad.

By its *HR structure* - as PhD researchers, scientists, doctoral students, master students and associated professors - Icpe has the scientific expertise to approach research topics of national European level:

- electric vehicle,
- electric propulsion systems for boats,
- smart house, technologies for environmental protection,
- monitoring of environmental factors in the biological reservation (the Danube Delta Biosphere Reservation),
- technology for a sustainable economic development and renewable energy,
- new ecological and biodegradable materials,
- medical equipment,
- IT applications, etc.

EEA fondată în 1950

ELECTROTEHNICĂ, ELECTRONICĂ, AUTOMATICĂ

Publicație trimestrială a ICPE

ISSN 1582-5175

vol. 66 nr. 2 aprilie-iunie 2018

Scopul revistei

Revista EEA își propune să publice numai acele articole care atât prin ideile noi, cât și prin rezultatele prezentate, să aducă contribuții importante la cercetarea românească de avangardă din electrotehnică, electronică, automatică, informatică și din celelalte domenii ale științelor inginerești.

Articolele, publicate în două versiuni pe suport de hârtie și online, sunt identice. Accesul liber online asigură o mare vizibilitate articolelor.

Prezentare

Revista EEA a fost fondată în anul **1950** sub numele de „Electricitatea" (ISSN 1220-2533; vol. 1-3) care, în 1953, și-a schimbat numele în „Electrotehnica" (ISSN 0013-5321; vol. 1-22), care, în 1975, după integrarea „Automatica și Electronica (ISSN 1220-2584) apare cu numele actual **Electrotehnică, Electronică, Automatică (EEA)** [**ISSN 1582-5175; e-ISSN 2392-828X**] (pentru detalii, a se naviga pe site-ul www.eea-journal.ro).

Încă de la primele numere, deși era unica revistă specializată din domeniul electrotehnicii, EEA a fost constant apreciată pentru nivelul științific ridicat al articolelor publicate.

În prezent, EEA este recunoscută ca lider printre publicațiile științifice, pentru calitatea și standardele înalte ale articolelor apărute în domeniul științelor inginerești. Printre autori se numără specialiști, cercetători și cadre didactice din Algeria, Belgia, R.P. China, Finlanda, Franța, Germania, Italia, Moldova, Serbia, Slovacia, Spania, Ungaria etc.

În paginile revistei, se regăsesc lucrări științifice originale care nu au mai fost publicate și care nu sunt luate în considerare pentru publicare în altă parte, cât și articolele prezentate la conferințe, cu condiția să nu fi fost publicate (parțial sau integral) în volumele manifestărilor științifice (min. 6 pagini-max. 16 pagini), sinteze ale unor proiecte de cercetare, dezbateri științifice și sinteze pe teme prioritare din cercetarea fundamentală și aplicativă (max. 20 pagini), recenzii / note de lectură ale celor mai recente apariții de cărți tehnico-științifice (max. 1 pagină), liste de resurse bibliografice comentate din domeniul științelor inginerești (max. 8 pagini).

Pentru a dovedi deschiderea către noile domenii de frontieră, Colegiul editorial a creat o secțiune-varia (*Miscellanea Section*), în care sunt publicate articole a căror tematică aparține altor domenii (matematică, științe socio-umane, științe economice, științele vieții și ale pământului (inclusiv mediul), științe agricole, științe medicale etc.) și care, *tangențial*, pot fi corelate cu domeniul științelor inginerești datorită viziunii, conexiunilor și al abordării inedite a subiectelor.

Revista are un *Colegiu de redacție* format din academicieni, profesori universitari și cercetători științifici din România și din străinătate – personalități recunoscute din domeniul științelor inginerești (în special, din electrotehnică, electronică, automatică și din celelalte domenii ale ingineriei).

Revista EEA este clasificată **B⁺** de Consiliul Național al Cercetării Științifice din Învățământul Superior (CNCSIS) și este indexată în bazele internaționale de date: Elsevier, Scopus, Compendex, ProQuest, EBSCO, Ulrich's, Index Copernicus International. În prezent, este în proces de evaluare de Thomson Reuters - ISI.

Scope

The EEA Journal aims to publish only those papers that by the new ideas and the results shown to bring significant contributions to research in the Romanian avant-garde engineering as electrical engineering, electronics, automation and other engineering sciences.

The papers, published in two versions on paper and online, are identical. The online open access ensures a high visibility of the papers.

Description

The EEA Journal is founded in **1950** under the title „Electricitatea" (ISSN 1220-2533; vol. 1-3) that, in 1953, changed its title in „Electrotehnica" (ISSN 0013-5321; vol. 1-22) that, in 1975, after merging „Automatica și Electronica (ISSN 1220-2584) is published under the present title **Electrotehnica, Electronica, Automatica (EEA)** [**ISSN 1582-5175; e-ISSN 2392-828X**] (for further details, please navigate on the site www.eea-journal.ro).

Since the early issues, although it was the only scientific journal specialized in the field of electrical engineering, the EEA has been consistently highly rated for the level of its scientific papers.

At present, the EEA is recognized as a leader among the scientific publications for the quality and high standards of the papers belonging to the field of engineering sciences. The authors are specialists, researchers and academics from Algeria, Belgium, PR of China, Finland, France, Germany, Italy, Moldova, Serbia, Slovakia, Spain, Hungary, etc.

In the EEA, there are published original papers that haven't been previously published and are not under consideration for publication somewhere else, as well as papers presented at conferences, only if they have not been published (partially or fully) in the proceedings of that scientific event (min. 6 pages, max. 16 pages), syntheses of research projects, scientific debates and syntheses on priority themes of fundamental and applied research (max. 20 pages), reviews / reading notes of the latest scientific and technical books (max. 1 page), commented lists of bibliographic resources in engineering sciences (max. 8 pages).

To prove the openness to new frontier areas, the Editorial Board has created a *varia* section (*Miscellanea Section*) for papers belonging to other thematic areas (mathematics, social studies, economics, life and earth sciences (including the environment), agricultural sciences, medical sciences, etc.) and, *tangentially*, they are related to engineering sciences thanks to vision, connections and novel approach of the topics.

The *Editorial Board* includes academicians, university professors and researchers from Romania and abroad that are well-known personalities in the field of engineering sciences (especially, in electrical, electronics, automation, computer science and other fields of engineering).

The EEA journal is included in the **B⁺** category by the National Council of Scientific Research in Higher Education (CNCSIS) and indexed in international data bases: Elsevier, Scopus, Compendex, ProQuest, EBSCO, Ulrich's, Index Copernicus International. Currently, EEA is under evaluation by Thomson Reuters – ISI.

ELECTRA EDITURA

ICPE

EEA

fondată în 1950

ELECTROTEHNICĂ, ELECTRONICĂ, AUTOMATICĂ

vol. 66 nr. 2 aprilie-iunie 2018 publicație a ICPE ISSN: 1582-5175

Revista EEA este clasificată B+ de CNCSIS și indexată în bazele internaționale de date:
Elsevier, Scopus, Compendex, ProQuest, EBSCO, Ulrich's, Index Copernicus International

pag. **Articole**

[Continuare pe coperta 4]

EEA fondată în 1950

ELECTROTEHNICĂ, ELECTRONICĂ, AUTOMATICĂ

pag. Articole

Miscellanea Section

* * *

www.icpe.ro

ISSN 1582-5175

9 771582 517002

Redacţia EEA-Journal

Splaiul Unirii, nr. 313; 030138 Bucureşti, România
Tel. +4021 589 33 00 | Mobil: +40749 070 395
e-mail: eea-journal@icpe.ro
Internet: www.eea-journal.ro

EEA *fondată în 1950*
ELECTROTEHNICĂ, ELECTRONICĂ, AUTOMATICĂ

Publicație trimestrială a ICPE

ISSN 1582-5175

"TECHNOLOGIES FOR A **SUSTAINABLE DEVELOPMENT**"

www.icpe.ro

Icpe was founded by the Government Decision no. 868 of 5 August 1950 (under the name „Institutul de cercetări electrotehnice" [Institute of Electrical Research]).

Icpe is a complex structure that covers a wide range of innovative activities connected via the electric profile:

- **R & D** in the national and international programmes of promoting the sustainable development technologies in over 500 research projects.
- **PRODUCTION**: special electric machines, DC & brushless actuators, ecological electric equipment (circuit breakers, contactors, fuses), cables and special electric conductors.
- **SERVICES**:

Metrology (thermal expertise of buildings, thermography (thermal imaging), noise measurement, measurement of electromagnetic disturbances);

Material characterization for determining the electric properties, mechanical properties, thermal properties and the resistance to the environmental factors;

Renewable energy in several systems: photovoltaic, wind, solar-thermal, biomass, biogas, biofuel;

Integrated energy services by energy audit, energy supply;

Consulting services (pre-feasibility studies, feasibility and project studies, evaluation of project proposals, technical projects and implementation, energy management, technical control);

"ELECTRA" Publishing House (founded in 1993) is listed among the publishers recognized by CNCS [National Council of R&D and High Education], starting 2001. So far, 300 technical and beyond books have been published. It is the editor of the journal *EEA*

The Technological Information Centre helps in the innovation implementation in economy and society by the dissemination information of the R&D results, technological documentation and operators training in order to facilitate the capitalization results.

Icpe is a brand on the Romanian market and abroad.

By its *HR structure* - as PhD researchers, scientists, doctoral students, master students and associated professors - Icpe has the scientific expertise to approach research topics of national European level:

- electric vehicle,
- electric propulsion systems for boats,
- smart house, technologies for environmental protection,
- monitoring of environmental factors in the biological reservation (the Danube Delta Biosphere Reservation),
- technology for a sustainable economic development and renewable energy,
- new ecological and biodegradable materials,
- medical equipment,
- IT applications, etc.

EEA fondată în 1950 ELECTROTEHNICĂ, ELECTRONICĂ, AUTOMATICĂ

Publicație trimestrială a ICPE

ISSN 1582-5175

vol. 66 nr. 2 aprilie-iunie 2018

Scopul revistei

Revista EEA își propune să publice numai acele articole care atât prin ideile noi, cât și prin rezultatele prezentate, să aducă contribuții importante la cercetarea românească de avangardă din electrotehnică, electronică, automatică, informatică și din celelalte domenii ale științelor inginerești.

Articolele, publicate în două versiuni pe suport de hârtie și online, sunt identice. Accesul liber online asigură o mare vizibilitate articolelor.

Prezentare

Revista EEA a fost fondată în anul **1950** sub numele de „Electricitatea" (ISSN 1220-2533; vol. 1-3) care, în 1953, și-a schimbat numele în „Electrotehnica" (ISSN 0013-5321; vol. 1-22), care, în 1975, după integrarea „Automatica și Electronica (ISSN 1220-2584) apare cu numele actual **Electrotehnică, Electronică, Automatică (EEA)** [ISSN 1582-5175; e-ISSN 2392-828X] (pentru detalii, a se naviga pe site-ul www.eea-journal.ro).

Încă de la primele numere, deși era unica revistă specializată din domeniul electrotehnicii, EEA a fost constant apreciată pentru nivelul științific ridicat al articolelor publicate.

În prezent, EEA este recunoscută ca lider printre publicațiile științifice, pentru calitatea și standardele înalte ale articolelor apărute în domeniul științelor inginerești. Printre autori se numără specialiști, cercetători și cadre didactice din Algeria, Belgia, R.P. China, Finlanda, Franța, Germania, Italia, Moldova, Serbia, Slovacia, Spania, Ungaria etc.

În paginile revistei, se regăsesc lucrări științifice originale care nu au mai fost publicate și care nu sunt luate în considerare pentru publicare în altă parte, cât și articolele prezentate la conferințe, cu condiția să nu fi fost publicate (parțial sau integral) în volumele manifestărilor științifice (min. 6 pagini-max. 16 pagini), sinteze ale unor proiecte de cercetare, dezbateri științifice și sinteze pe teme prioritare din cercetarea fundamentală și aplicativă (max. 20 pagini), recenzii / note de lectură ale celor mai recente apariții de cărți tehnico-științifice (max. 1 pagină), liste de resurse bibliografice comentate din domeniul științelor inginerești (max. 8 pagini).

Pentru a dovedi deschiderea către noile domenii de frontieră, Colegiul editorial a creat o secțiune-varia (*Miscellanea Section*), în care sunt publicate articole a căror tematică aparține altor domenii (matematică, științe socio-umane, științe economice, științele vieții și ale pământului (inclusiv mediul), științe agricole, științe medicale etc.) și care, *tangențial*, pot fi corelate cu domeniul științelor inginerești datorită viziunii, conexiunilor și al abordării inedite a subiectelor.

Revista are un *Colegiu de redacție* format din academicieni, profesori universitari și cercetători științifici din România și din străinătate – personalități recunoscute din domeniul științelor inginerești (în special, din electrotehnică, electronică, automatică și din celelalte domenii ale ingineriei).

Revista EEA este clasificată B⁺ de Consiliul Național al Cercetării Științifice din Învățământul Superior (CNCSIS) și este indexată în bazele internaționale de date: Elsevier, Scopus, Compendex, ProQuest, EBSCO, Ulrich's, Index Copernicus International. În prezent, este în proces de evaluare de Thomson Reuters - ISI.

Scope

The EEA Journal aims to publish only those papers that by the new ideas and the results shown to bring significant contributions to research in the Romanian avant-garde engineering as electrical engineering, electronics, automation and other engineering sciences.

The papers, published in two versions on paper and online, are identical. The online open access ensures a high visibility of the papers.

Description

The EEA Journal is founded in **1950** under the title „Electricitatea" (ISSN 1220-2533; vol. 1-3) that, in 1953, changed its title in „Electrotehnica" (ISSN 0013-5321; vol. 1-22) that, in 1975, after merging „Automatica și Electronica (ISSN 1220-2584) is published under the present title **Electrotehnica, Electronica, Automatica (EEA)** [ISSN 1582-5175; e-ISSN 2392-828X] (for further details, please navigate on the site www.eea-journal.ro).

Since the early issues, although it was the only scientific journal specialized in the field of electrical engineering, the EEA has been consistently highly rated for the level of its scientific papers.

At present, the EEA is recognized as a leader among the scientific publications for the quality and high standards of the papers belonging to the field of engineering sciences. The authors are specialists, researchers and academics from Algeria, Belgium, PR of China, Finland, France, Germany, Italy, Moldova, Serbia, Slovakia, Spain, Hungary, etc.

In the EEA, there are published original papers that haven't been previously published and are not under consideration for publication somewhere else, as well as papers presented at conferences, only if they have not been published (partially or fully) in the proceedings of that scientific event (min. 6 pages, max. 16 pages), syntheses of research projects, scientific debates and syntheses on priority themes of fundamental and applied research (max. 20 pages), reviews / reading notes of the latest scientific and technical books (max. 1 page), commented lists of bibliographic resources in engineering sciences (max. 8 pages).

To prove the openness to new frontier areas, the Editorial Board has created a *varia* section (*Miscellanea Section*) for papers belonging to other thematic areas (mathematics, social studies, economics, life and earth sciences (including the environment), agricultural sciences, medical sciences, etc.) and, *tangentially*, they are related to engineering sciences thanks to vision, connections and novel approach of the topics.

The *Editorial Board* includes academicians, university professors and researchers from Romania and abroad that are well-known personalities in the field of engineering sciences (especially, in electrical, electronics, automation, computer science and other fields of engineering).

The EEA journal is included in the B⁺ category by the National Council of Scientific Research in Higher Education (CNCSIS) and indexed in international data bases: Elsevier, Scopus, Compendex, ProQuest, EBSCO, Ulrich's, Index Copernicus International. Currently, EEA is under evaluation by Thomson Reuters – ISI.

ELECTRA EDITURA

ICPE

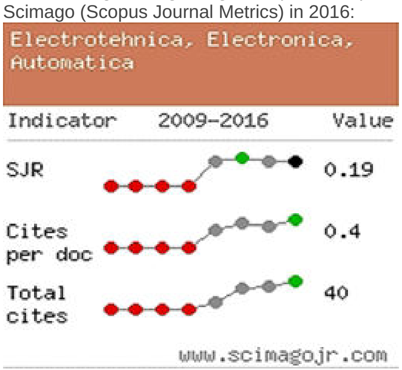
Home

Electrotehnică, Electronică, Automatică (EEA)
Founded in 1950
The new series since 1974

The **Electrotehnică, Electronică, Automatică (EEA)** [Electrical Engineering, Electronics, Automation] is a scientific journal publishing papers in the field of the engineering both in print and online.
The print and online versions of all papers are identical.
The online open access ensures a high visibility of the papers.
print ISSN: 1582-5175
online ISSN: 2392-828X

Issues per year: 4

Indexed and abstracted in:
Elsevier, Engineering Village, Scopus, Compendex, ProQuest, ProQuest-Ulrich's, EBSCO, Index Copernicus
Scimago (Scopus Journal Metrics) in 2016:



(source: http://www.scimagojr.com/journalsearch.php?q=21100255070&tip=sid&clean=0)

Sponsorship
Publisher: Electra Publishing House
Financial backing: Icpe SA

Editorial Office:
Editura ELECTRA
Splaiul Unirii, nr. 313; 030138 București
Tel.: +4021 589 34 82
Mobile: +40749 070 395
e-mail: eea-journal@icpe.ro
internet: www.eea-journal.ro

About

The **Electrotehnică, Electronică, Automatică (EEA)** [Electrical Engineering, Electronics, Automation] is a peer-reviewed scientific journal in the field of the engineering published by "Electra" Publishing House (as part of Icpe).

Scope
The EEA Journal aims to publish only those papers that by the new ideas and the results shown to bring significant contributions to research in the Romanian and international avant-garde engineering as electrical engineering, electronics, automation and other engineering sciences.

Abstracting and indexing
The EEA journal is included in the B+ category by the National Council of Scientific Research in Higher Education (CNCSIS) and indexed in international databases:
Ulrichsweb.com™ (1997-present) (Since 2007, Ulrich's becomes a part of Serials Solutions in the ProQuest family.)
Index Copernicus International (2009)
Elsevier- Engineering Village-Scopus (2012)
Elsevier- Engineering Village-Compendex (2012)
ProQuest (2010)
EBSCO (2014)
Currently, EEA is under evaluation by Thomson Reuters - ISI.

Description
The EEA Journal is founded in **1950** under the name „Electricitatea" (ISSN 1220-2533; vol. 1-3) that, in 1953, changed its name in „Electrotehnica" (ISSN 0013-5321; vol. 1-22) that, in 1975, after including „Automatica și Electronica (ISSN 1220-2584), is published under the present name „Electrotehnica, Electronica, Automatica (EEA)" (for further details, please read "History" and "Journal Genealogy" on this site).
Since the early issues, although it was the only scientific journal specialized in the field of electrical engineering, and the EEA has been highly rated thanks to the scientific level of its papers.
The Editorial Board includes academicians, university professors and researchers from Romania and abroad that are well-known personalities in the field of engineering sciences (especially, in electrical, electronics, automation, computer science and other fields of engineering, etc.).
At present, the EEA is recognized as a leader among the scientific publications for the quality and high standards of the papers belonging to the field of engineering sciences. The authors are specialists, researchers and academics from Algeria, Belgium, PR of China, Finland, France, Germany, Italy, Moldova, Slovakia, Hungary, etc.
In the EEA, there are published original papers, that haven't been previously published and are not under consideration for publication somewhere else, as well as papers presented at conferences only if they have not been published (partially or fully) in the proceedings of that scientific event (min. 6 pages, max. 16 pages), syntheses of research projects, scientific debates and syntheses on priority themes of fundamental and applied research (max. 20 pages), reviews / reading notes of the latest scientific and technical books (max. 1 page), commented lists of bibliographic resources in engineering sciences (max. 8 pages).
Papers should be written in English.

Subcategories »
- History
- Journal Genealogy

EEA

fondată în 1950

ELECTROTEHNICĂ, ELECTRONICĂ, AUTOMATICĂ

vol. 66 nr. 2 aprilie-iunie 2018 publicaţie a ICPE ISSN: 1582-5175

Revista EEA este clasificată B+ de CNCSIS şi indexată în bazele internaţionale de date:
Elsevier, Scopus, Compendex, ProQuest, EBSCO, Ulrich's, Index Copernicus International

pag. **Articole**

[Continuare pe coperta 4]

EEA

fondată în 1950

ELECTROTEHNICĂ, ELECTRONICĂ, AUTOMATICĂ

pag. **Articole**

Miscellanea Section

* * *

ICPE
www.icpe.ro

ISSN 1582-5175
9 771582 517002

Redacţia EEA-Journal

Splaiul Unirii, nr. 313; 030138 Bucureşti, România
Tel. +4021 589 33 00 | Mobil: +40749 070 395
e-mail: eea-journal@icpe.ro
Internet: www.eea-journal.ro

EEA fondată în 1950
ELECTROTEHNICĂ, ELECTRONICĂ, AUTOMATICĂ

Publicație trimestrială
a ICPE

ISSN 1582-5175

ICPE

"TECHNOLOGIES FOR A **SUSTAINABLE DEVELOPMENT**"

www.icpe.ro

Icpe was founded by the Government Decision no. 868 of 5 August 1950 (under the name „Institutul de cercetări electrotehnice" [Institute of Electrical Research]).

Icpe is a complex structure that covers a wide range of innovative activities connected via the electric profile:

- **R & D** in the national and international programmes of promoting the sustainable development technologies in over 500 research projects.
- **PRODUCTION**: special electric machines, DC & brushless actuators, ecological electric equipment (circuit breakers, contactors, fuses), cables and special electric conductors.
- **SERVICES**:

Metrology (thermal expertise of buildings, thermography (thermal imaging), noise measurement, measurement of electromagnetic disturbances);

Material characterization for determining the electric properties, mechanical properties, thermal properties and the resistance to the environmental factors;

Renewable energy in several systems: photovoltaic, wind, solar-thermal, biomass, biogas, biofuel;

Integrated energy services by energy audit, energy supply;

Consulting services (pre-feasibility studies, feasibility and project studies, evaluation of project proposals, technical projects and implementation, energy management, technical control);

"ELECTRA" Publishing House (founded in 1993) is listed among the publishers recognized by CNC [National Council of R&D and High Education], starting 2001. So far, 300 technical and beyond books have been published. It is the editor of th journal *EEA*

The Technological Information Centre helps in th innovation implementation in economy and society by the dissemination information of the R&D results, technological documentation and operators training in order to facilitate the capitalization results.

Icpe is a brand on the Romanian market and abroad.

By its *HR structure* - as PhD researchers, scientists, doctoral students, master students and associated professors - Icpe has the scientific expertise to approach research topics of national o European level:

- electric vehicle,
- electric propulsion systems for boats,
- smart house, technologies for environmental protection,
- monitoring of environmental factors in the biological reservation (the Danube Delta Biosphere Reservation),
- technology for a sustainable economic development and renewable energy,
- new ecological and biodegradable materials,
- medical equipment,
- IT applications, etc.

EEA *fondată în 1950*

ELECTROTEHNICĂ, ELECTRONICĂ, AUTOMATICĂ

Publicație trimestrială a ICPE

ISSN 1582-5175

vol. 66 nr. 2 aprilie-iunie 2018

Scopul revistei

Revista EEA își propune să publice numai acele articole care atât prin ideile noi, cât și prin rezultatele prezentate, să aducă contribuții importante la cercetarea românească de avangardă din electrotehnică, electronică, automatică, informatică și din celelalte domenii ale științelor inginerești.

Articolele, publicate în două versiuni pe suport de hârtie și online, sunt identice. Accesul liber online asigură o mare vizibilitate articolelor.

Prezentare

Revista EEA a fost fondată în anul 1950 sub numele de „Electricitatea" (ISSN 1220-2533; vol. 1-3) care, în 1953, și-a schimbat numele în „Electrotehnica" (ISSN 0013-5321; vol. 1-22), care, în 1975, după integrarea „Automatica și Electronica (ISSN 1220-2584) apare cu numele actual **Electrotehnică, Electronică, Automatică (EEA)** [ISSN 1582-5175; e-ISSN 2392-828X] (pentru detalii, a se naviga pe site-ul www.eea-journal.ro).

Încă de la primele numere, deși era unica revistă specializată din domeniul electrotehnicii, EEA a fost constant apreciată pentru nivelul științific ridicat al articolelor publicate.

În prezent, EEA este recunoscută ca lider printre publicațiile științifice, pentru calitatea și standardele înalte ale articolelor apărute în domeniul științelor inginerești. Printre autori se numără specialiști, cercetători și cadre didactice din Algeria, Belgia, R.P. China, Finlanda, Franța, Germania, Italia, Moldova, Serbia, Slovacia, Spania, Ungaria etc.

În paginile revistei, se regăsesc lucrări științifice originale care nu au mai fost publicate și care nu sunt luate în considerare pentru publicare în altă parte, cât și articolele prezentate la conferințe, cu condiția să nu fi fost publicate (parțial sau integral) în volumele manifestărilor științifice (min. 6 pagini-max. 16 pagini), sinteze ale unor proiecte de cercetare, dezbateri științifice și sinteze pe teme prioritare din cercetarea fundamentală și aplicativă (max. 20 pagini), recenzii / note de lectură ale celor mai recente apariții de cărți tehnico-științifice (max. 1 pagină), liste de resurse bibliografice comentate din domeniul științelor inginerești (max. 8 pagini).

Pentru a dovedi deschiderea către noile domenii de frontieră, Colegiul editorial a creat o secțiune-varia (*Miscellanea Section*), în care sunt publicate articole a căror tematică aparține altor domenii (matematică, științe socio-umane, științe economice, științele vieții și ale pământului (inclusiv mediul), științe agricole, științe medicale etc.) și care, *tangențial*, pot fi corelate cu domeniul științelor inginerești datorită viziunii, conexiunilor și al abordării inedite a subiectelor.

Revista are un *Colegiu de redacție* format din academicieni, profesori universitari și cercetători științifici din România și din străinătate – personalități recunoscute din domeniul științelor inginerești (în special, din electrotehnică, electronică, automatică și din celelalte domenii ale ingineriei).

Revista EEA este clasificată B+ de Consiliul Național al Cercetării Științifice din Învățământul Superior (CNCSIS) și este indexată în bazele internaționale de date: Elsevier, Scopus, Compendex, ProQuest, EBSCO, Ulrich's, Index Copernicus International. În prezent, este în proces de evaluare de Thomson Reuters - ISI.

Scope

The EEA Journal aims to publish only those papers that by the new ideas and the results shown to bring significant contributions to research in the Romanian avant-garde engineering as electrical engineering, electronics, automation and other engineering sciences.

The papers, published in two versions on paper and online, are identical. The online open access ensures a high visibility of the papers.

Description

The EEA Journal is founded in 1950 under the title „Electricitatea" (ISSN 1220-2533; vol. 1-3) that, in 1953, changed its title in „Electrotehnica" (ISSN 0013-5321; vol. 1-22) that, in 1975, after merging „Automatica și Electronica (ISSN 1220-2584) is published under the present title **Electrotehnica, Electronica, Automatica (EEA)** [ISSN 1582-5175; e-ISSN 2392-828X] (for further details, please navigate on the site www.eea-journal.ro).

Since the early issues, although it was the only scientific journal specialized in the field of electrical engineering, the EEA has been consistently highly rated for the level of its scientific papers.

At present, the EEA is recognized as a leader among the scientific publications for the quality and high standards of the papers belonging to the field of engineering sciences. The authors are specialists, researchers and academics from Algeria, Belgium, PR of China, Finland, France, Germany, Italy, Moldova, Serbia, Slovakia, Spain, Hungary, etc.

In the EEA, there are published original papers that haven't been previously published and are not under consideration for publication somewhere else, as well as papers presented at conferences, only if they have not been published (partially or fully) in the proceedings of that scientific event (min. 6 pages, max. 16 pages), syntheses of research projects, scientific debates and syntheses on priority themes of fundamental and applied research (max. 20 pages), reviews / reading notes of the latest scientific and technical books (max. 1 page), commented lists of bibliographic resources in engineering sciences (max. 8 pages).

To prove the openness to new frontier areas, the Editorial Board has created a *varia* section (*Miscellanea Section*) for papers belonging to other thematic areas (mathematics, social studies, economics, life and earth sciences (including the environment), agricultural sciences, medical sciences, etc.) and, *tangentially*, they are related to engineering sciences thanks to vision, connections and novel approach of the topics.

The *Editorial Board* includes academicians, university professors and researchers from Romania and abroad that are well-known personalities in the field of engineering sciences (especially, in electrical, electronics, automation, computer science and other fields of engineering).

The EEA journal is included in the B+ category by the National Council of Scientific Research in Higher Education (CNCSIS) and indexed in international data bases: Elsevier, Scopus, Compendex, ProQuest, EBSCO, Ulrich's, Index Copernicus International. Currently, EEA is under evaluation by Thomson Reuters – ISI.

ELECTRA EDITURA

ICPE

Contents

Miscellanea Section

2018 | vol. 66 | nr. 2 |

Contents

Miscellanea Section

Contents

Miscellanea Section

EEA_2-2018

« Parent category

- EEA_2018

Subcategories »

- Cover_2-2018
- art 01_2-2018-p005
- art 02_2-2018-p012
- art 03_2-2018-p018
- art 04_2-2018-p025
- art 05_2-2018-p031
- art 06_2-2018-p037
- art 07_2-2018-p045
- art 08_2-2018-p051
- art 09_2-2018-p057
- art 10_2-2018-p061
- art 11_2-2018-p069
- art 12_2-2018-p076
- art 13_2-2018-p081
- art 14_2-2018-p088
- art 15_2-2018-p094
- art 16_2-2018-p104
- art 17_2-2018-p111
- art 18_2-2018-p121
- art 19_2-2018-p129
- art 20_2-2018-p135

EEA fondată în 1950 ELECTROTEHNICĂ, ELECTRONICĂ, AUTOMATICĂ

Publicaţie trimestrială a ICPE

ISSN 1582-5175

Editor-in-Chief
Elena POPA, senior scientist

Sponsorship:
Publisher: Editura „ELECTRA" (as part of Icpe SA)
Issuing body: Icpe SA

Editorial Office:
Editura „ELECTRA"
Splaiul Unirii, nr. 313; 030138 Bucureşti, România
Tel.: +4021 589 34 82 // Mobile: +40749 070 395
e-mail: eea-journal@icpe.ro
internet: www.eea-journal.ro

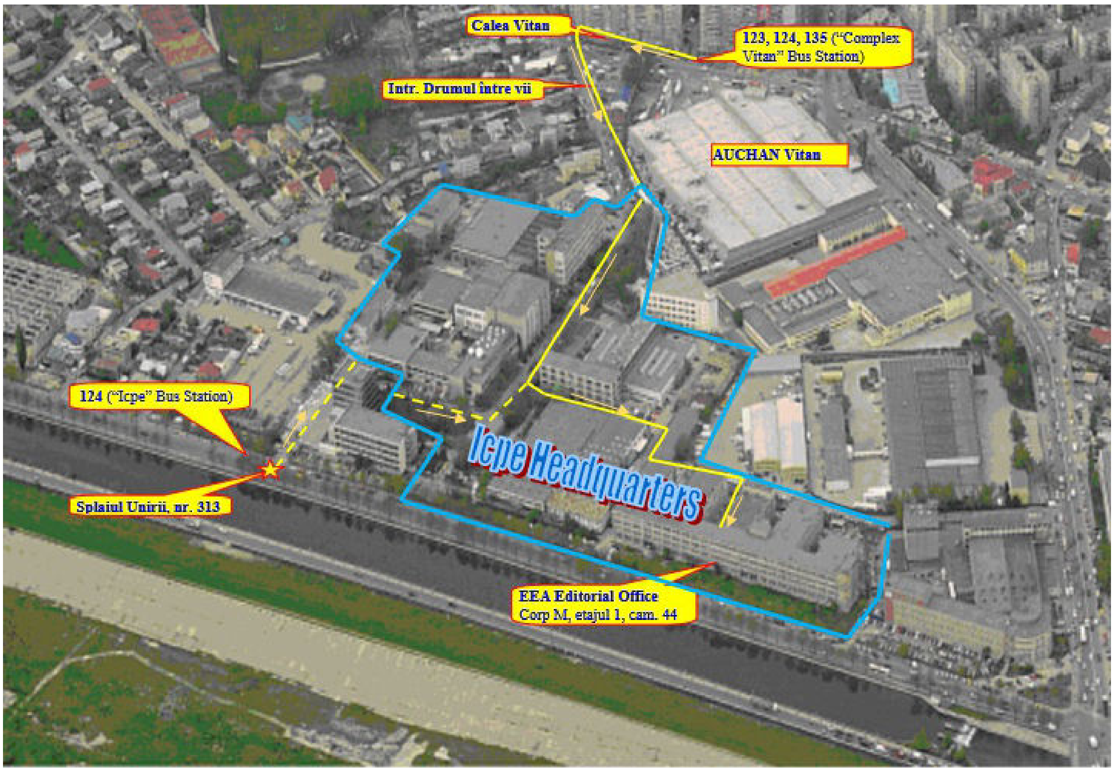
ICPE

ELECTRA EDITURA

EEA fondată în 1950
ELECTROTEHNICĂ, ELECTRONICĂ, AUTOMATICĂ
Part of ICPE

Search...

Contact



Editorial Office of EEA Journal
Postal Address: Splaiul Unirii, nr. 313, 030138-Bucureşti, România
Tel.: +4021 589 34 82
Mobile: +40749 070 395
e-mail: eea-journal@icpe.ro
internet: www.eea-journal.ro

Editor-in-Chief

Elena POPA, Senior Scientist
e-mail: elena.popa@icpe.ro

Web Designer

Viorel LUNGU, Math.
e-mail: livio@icpe.ro

EEA - Electrotehnica, Electronica, Automatica

COUNTRY

Romania

Universities and research institutions in Romania

SUBJECT AREA AND CATEGORY

Engineering
- Control and Systems Engineering
- Electrical and Electronic Engineering

PUBLISHER

Institutul de Cercetare si Proiectare pentru Electrotehnica

H-INDEX

16

PUBLICATION TYPE

Journals

ISSN

15825175

COVERAGE

2012-2021

INFORMATION

Homepage

How to publish in this journal

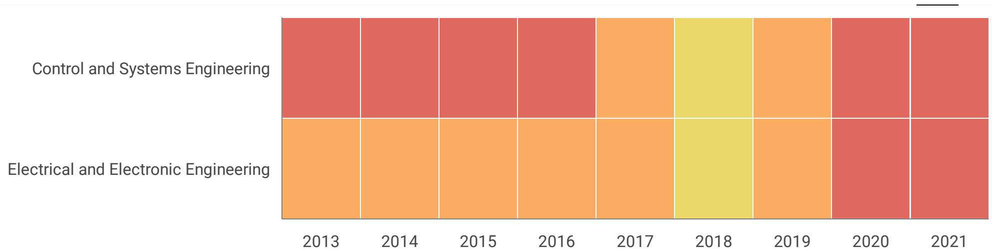
eea-journal@icpe.ro

SCOPE

The EEA Journal aims to publish only those papers that by the new ideas and the results shown to bring significant contributions to research in the Romanian and international avant-garde engineering as electrical engineering, electronics, automation and other engineering sciences.

Join the conversation about this journal

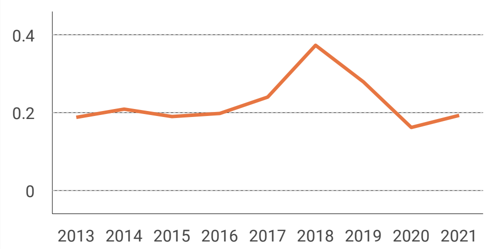
Quartiles



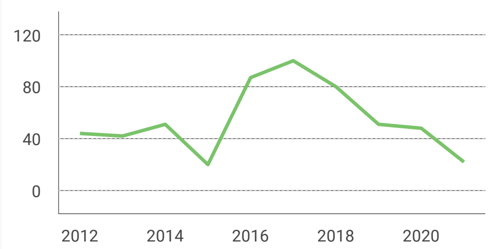
FIND SIMILAR JOURNALS ? options

1	2
Journal of The Institution of Engineers (India): Series B	**Electrical Engineering**
IND	DEU
28% similarity	**26%** similarity

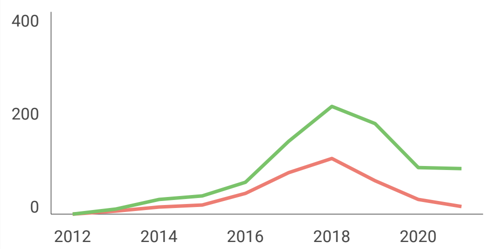
SJR



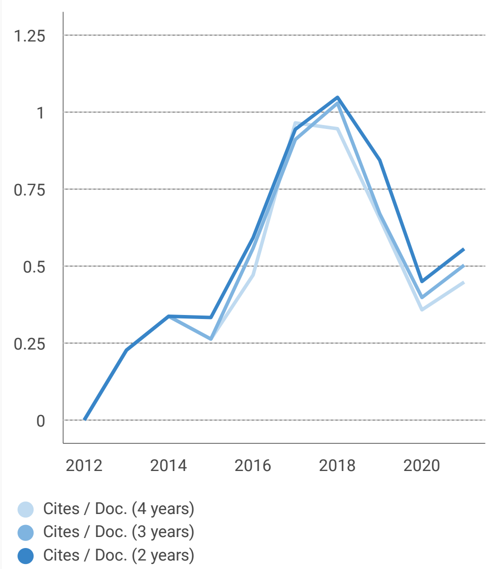
Total Documents



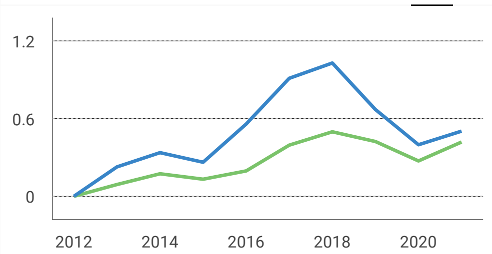
Total Cites Self-Cites



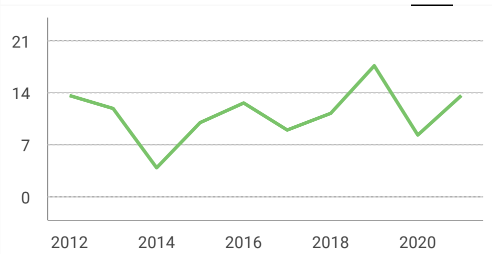
Citations per document



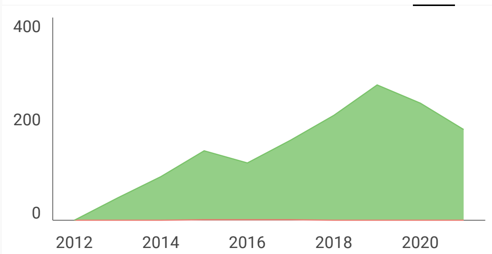
External Cites per Doc Cites per Doc



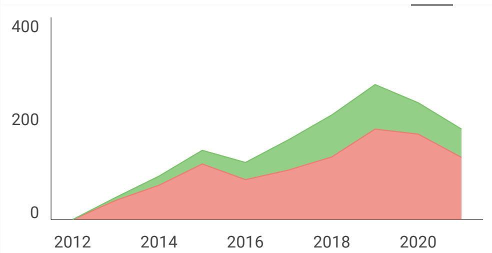
% International Collaboration



Citable documents Non-citable documents



Cited documents Uncited documents



← Show this widget in your own website

Just copy the code below and paste within your html code:

<a href="https://www.scimag

Metrics based on Scopus® data as of April 2022

D

DIB Djalel 3 years ago

Hello
I want to know how to submit a paper in this Journal "Electrotehnica, Electronica, Automatica"
link or email.
thank you

reply

SCImago Team

Melanie Ortiz 3 years ago

Dear Dib Djalel, thank you very much for your comment, we suggest you look for author's instructions/submission guidelines in the journal's website. Best Regards, SCImago Team

Y

Yacine 4 years ago

Dear sir I have sent you an article entitled "study Expérimentation for thé système if poursuit (traveling) Auresolar" on 27/06/2018 and recoller on 19/10/2018. But I didnt receive any message from you about the situation of my article.
If possible to informé me about it.
Salutations

reply

E

El Khansa Bdirina 4 years ago

Dear sir I have sent you an article entitled:
on the enhancement of MPC technique without relaxing constraints on control action on 5/9/2018
But i didnt receive any message from you about the situation of my article.
If possible to informe me about it.
Salutations

reply

SCImago Team

Elena Corera 4 years ago

Please, check out our FAQs https://www.scimagojr.com/help.php?q=FAQ

A

asma 4 years ago

I am a student in doctorat and i aspire to receive my acceptance of you?

reply

Leave a comment

Name

Email
(will not be published)

I'm not a robot

reCAPTCHA
Privacy - Terms

Submit

The users of Scimago Journal & Country Rank have the possibility to dialogue through comments linked to a specific journal. The purpose is to have a forum in which general doubts about the processes of publication in the journal, experiences and other issues derived from the publication of papers are resolved. For topics on particular articles, maintain the dialogue through the usual channels with your editor.

Scopus Preview

Source details

Check whether you can access Scopus remotely through your institution

Maybe later | Check access

EEA - Electrotehnica, Electronica, Automatica

Scopus coverage years: from 2012 to 2022

Publisher: Institutul de Cercetare si Proiectare pentru Electrotehnica

ISSN: 1582-5175

Subject area: Engineering: Electrical and Electronic Engineering | Engineering: Control and Systems Engineering

Source type: Journal

View all documents > | Set document alert | Save to source list

CiteScore 2021
1.3

SJR 2021
0.193

SNIP 2021
0.325

CiteScore | CiteScore rank & trend | Scopus content coverage

Improved CiteScore methodology

CiteScore 2021 counts the citations received in 2018-2021 to articles, reviews, conference papers, book chapters and data papers published in 2018-2021, and divides this by the number of publications published in 2018-2021. Learn more >

CiteScore 2021

$$1.3 = \frac{259 \text{ Citations } 2018 - 2021}{201 \text{ Documents } 2018 - 2021}$$

Calculated on 05 May, 2022

CiteScoreTracker 2022

$$1.0 = \frac{174 \text{ Citations to date}}{175 \text{ Documents to date}}$$

Last updated on 05 January, 2023 • Updated monthly

CiteScore rank 2021

Category	Rank	Percentile
Engineering — Electrical and Electronic Engineering	#525/708	25th
Engineering — Control and Systems Engineering	#209/270	22nd

View CiteScore methodology > | CiteScore FAQ > | Add CiteScore to your site

2018 | vol. 66 | nr. 2 | art. 6

Investigation of Transformer Losses and Temperature Rise

Waluyo, Siti Saodah, Rohana

Abstract

Power and distribution transformers are very important equipment in a power system. In an application, they experience heating, due to loading. The heating temperature rise has correlations to the loading current, power losses, efficiency and surface area. This research investigated some relations among the power losses, temperature rises, efficiency and the leading current, based on the measurements and empirical approach. The results indicated that the total power and the core losses would increase as the temperature rise increased too, with the average of 0.25 kW/oC and 0.30 kW/oC respectively. The output power increased as the temperature rise rose, as 6.4 kW/oC. Nevertheless, the efficiency would reduce as the temperature rise increased as the average of -6.41 %/oC. The temperature rise was dominantly caused by the power losses, rather than the loading power. By all means, the power losses were significantly depending on the loading power.

Keywords: *efficiency, empirical, loading, power loss, transformer, temperature rise*

To cite this article: *Waluyo, Siti Saodah, Rohana, "Investigation of transformer losses and temperature rise", in Electrotehnica, Electronica, Automatica (EEA), 2018, vol. 66, no. 2, pp. 37-44, ISSN 1582-5175.*

Investigation of Transformer Losses and Temperature Rise

Waluyo[1*], Siti Saodah[2], Rohana[1]

[1]Department of Electrical Engineering, Institut Teknologi Nasional Bandung (ITENAS), Bandung, Indonesia
[2]Department of Energy Conversion, Politeknik Negeri Bandung (POLBAN), Bandung, Indonesia
*(corresponding author)

Abstract

Power and distribution transformers are very important equipment in a power system. In an application, they experience heating, due to loading. The heating temperature rise has correlations to the loading current, power losses, efficiency and surface area. This research investigated some relations among the power losses, temperature rises, efficiency and the leading current, based on the measurements and empirical approach. The results indicated that the total power and the core losses would increase as the temperature rise increased too, with the average of 0.25 kW/°C and 0.30 kW/°C respectively. The output power increased as the temperature rise rose, as 6.4 kW/°C. Nevertheless, the efficiency would reduce as the temperature rise increased as the average of -6.41 %/°C. The temperature rise was dominantly caused by the power losses, rather than the loading power. By all means, the power losses were significantly depending on the loading power.

Keywords: efficiency, empirical, loading, power loss, transformer, temperature rise

Received: February 14, 2018

To cite this article:
Waluyo, Siti Saodah, Rohana, "Investigation of transformer losses and temperature rise", in *Electrotehnica, Electronica, Automatica (EEA)*, 2018, vol. 66, no. 2, pp. 37-44, ISSN 1582-5175.

1. Introduction

Power and distribution transformers represent the largest portion of capital investment in transmission and distribution substations. Its importance is an obvious axiom in modern power systems. Transformer outages have a considerable economic impact on the power system operations. Transformers are major components in power systems [1-6]. Overloading of transformers can become necessary in open electricity markets due to economic reasons or simply to ensure continuous energy supply. During an overload circle accelerated ageing and damages have to be strictly avoided [7-8]. It was assessed the state of transformer research in some countries [9-10]. It is essential to carefully study its thermal behaviour [11-12]. One of the most important parameters governing a transformer's life expectancy is the hot-spot temperature (HST) value. The classical approach has been established to consider the hot-spot temperature as the sum of ambient temperature, top-oil temperature rise and hotspot-to-top-oil temperature gradient [13-16]. For transformer cooling when load changes, transformer oil is better than silicon oil [17-18]. The calculations were needed to design a transformer. The optimization algorithms improved the model adequacy, consistency as well as accuracy [19-20]. The toolbox using GUI has been developed for the transformer tests [21]. The model parameters and the precise calculation of power losses distribution were needed. The distribution and power transformers can be in the challenging future smart grid. [22-23]. The simulation of transitional airflow onto a flat plate of transformer was validated through the experiments. The no-load losses consisted by the hysteresis and eddy current losses [24-25]. The load loss of a transformer consists of losses due to ohmic resistance of windings and additional losses, such as stray losses. The temperature rise was caused by both Joules and stray losses. The ageing of transformers is influenced by short term and long term over loads, number and intensity of short circuits, incidence of lightning, and internal faults [26-29]. The consumers have become increasingly aware of fires and explosions involving oil-filled transformers located in power plants or substations. The winding loss was to add the obtained asymmetric magnetization current to the load currents [30-31].

There are two kinds of transformer thermal models, IEEE TOT/HST and ASU TOT/HST models [32]. The temperature rise test is to evaluate the methodology being currently used in the industry and to propose improvements by applying concise analysis, electrical power engineering principles and optimization theories in order to increase measurement accuracy while also reducing test performance times. The affecting factors of winding temperature rise are winding resistance, ambient temperature, oil temperature, load loss and core temperature [33-34]. The thermal effect, moisture, acidity, oxygen, etc were the controlling factor in determine transformer lifetime. For every 1 °C ambient temperature reduction, from standard 30 °C, releases approximately 1 % of overloading capability [35-36]. Thermal aspects affect transformer design. Therefore, the heat transfer at the winding surface is determined by the cooling conditions. Transformers ageing are one of the critical issues utilities [37-38]. The increased transformer loss caused by non-linear loads leads to an increase in transformer temperature, fatigue and premature failure. The losses in the windings and the core cause temperature rises in the materials. The most warm up parts of transformer were coils, and then core and oil [39-41]. The ONAN type transformers may lead to more general and more reliable recommendations regarding the influence of different heat sources space distribution.

The intensity of thermal ageing is dependent on the hot-spot temperature [42-43].

The limitation on the loss of life of the insulation and the winding hottest-spot temperature are the driving factors for overload limits. It gives a better understanding of the thermal performance of the transformer and it can be built up before the transformer is manufactured. The hot-spot temperature is not strongly influenced by the value of the hot-spot factor. The hotspot temperature of disc windings has a close relation with the transformer age due thermal behaviour. The degradation of electrical insulation in transformers is traced to thermoelectric processes. The hot spot temperature depends on instantaneous load, ambient temperature, winding design and cooling model. The oil temperature rise would be reduced by increasing the number of ribs and enlarging their dimensions. Dimensional changes made to the optimized cooling, increased oil cooling efficiency and significant cost savings. A monitoring system was considered essential to ensure reliability and sustainability of the transformer. Thermal design of oil-cooled transformers is generally done by empirical lumped parameter methods. Consideration of significant variation of ambient temperature into transformer thermal dynamics, seams a questionable from the thermodynamically point of view. Maximum hot-spot temperatures and relative loss of life may be underestimated when transformer operates under larger and severe overloads and with correlation between load and ambient temperature. If a transformer becomes too hot internally, then the insulation materials will degrade faster and the operating lifetime of the transformer will be shortened. Transformers in presence of winding short circuit faults are most important causes of failures. The estimating concept of overloading and thermal performance could be simplified as a thermal model. This is equivalent to limiting the aging acceleration factor (rate of loss of insulation life) to a pre-determined limit. The largest influence came from the top oil temperature where the variable viscosity test cases produced temperatures approximately 20 °C higher than the constant viscosity cases. The higher overload of the error is more pronounced as the oil viscosity effect [44-61].

Air temperature distribution was quite uniform but it possess a heat reservoir for the heated oil within the transformer. The loading guide offers relations for the calculation of the HST based on per-unit load. The insulation hot-spot temperature was the most critical quantity during transformer loading. The temperature was needed to consider when developing transformer-aging models. The top oil temperature and hot spot temperature as two criteria to evaluate the load ability and the insulation life of transformer. The effect of thermal stress was on the lifetime of the transformer [62-68].

The life of a transformer depends on the life of its insulation system and it is primarily dependent on transformer operating temperature.

The hottest-spot temperature and the exposed time reduce the mechanical tensile strength and the degree of polymerization of insulation. The hot-spot temperature values are used to calculate aging parameters, which include the aging acceleration factor, time dependent relative aging rate and insulation life loss. The loads or temperature ranges were wide or arithmetic it presents considerable values. The essential knowledge for a transformer reliable operation was achieved by using thermal transformer models.

The harmonic distortion can cause unnecessary winding loss and typical temperature rise, and decreases its life expectancy. [69-75]

The objective of research was to investigate the transformer losses and temperature rise based on the empirical equation and the sample of temperature measurements. Based on these parameters, it could be calculated the losses, output powers, and efficiency against to the temperature rises and the load currents.

2. Materials and Methods

The technical data of the transformer are 1 MVA, 50 Hz, 28.90 A, Dyn5 of vector group, 6.0 % of impedance, 2.52 tons. For this transformer, the nominal no load and load losses (P0 and Pk) were 2.3 kW and 9 kW respectively. Finally, by the calculation, the transformer surface area (At) was 117,684 cm^2.

The output power from the transformer was less than the input power. A much power distinction is converted into heat by core and winding losses. A combination of radiation and the heat dissipated is from the unprotected surface of transformer. The dissipated heat depends on the total surface area that is unprotected from the original core transformer and the total surface area that is not protected from the windings. The temperature rise in the transformer is difficult to predict precisely. One approach was to combine losses in the winding with core losses in transformers and assumed the heat energy dissipated uniformly through the surface to the core and winding of transformer at ambient temperature conditions. It is not a bad assumption considering most transformer surface area is the ferrite core winding rather than winding area with thermal conductivity (around 40 mW/cm/°C) is poor at any temperature. With these assumptions, the amount of temperature rise in a transformer could be calculated by the following formula [76].

$$\Delta T = \left(\frac{P\Sigma}{A_t}\right)^{0.833} \quad (1)$$

where ΔT, $P\Sigma$ and A_t were temperature rise (°C), total transformer losses (mW/cm2) and transformer surface area (cm^2).

$$P\Sigma = P_0 + P_k \quad (2)$$

where P_0 and P_k were no load and load losses respectively.

$$P_0 = \frac{V^2}{R_i} \quad (3)$$

$$P_k = kI^2 \quad (4)$$

For three phase power

$$P = \sqrt{3}\, V\, I \cos\phi \quad (5)$$

Power efficiency of transformer is

$$\eta = \frac{P_{out}}{P_{in}}\, x100\% \quad (6)$$

3. Calculation Results and Discussion

From the results of calculations, it could be calculated the power losses against the temperature rise which can be seen in Figure 1 below.

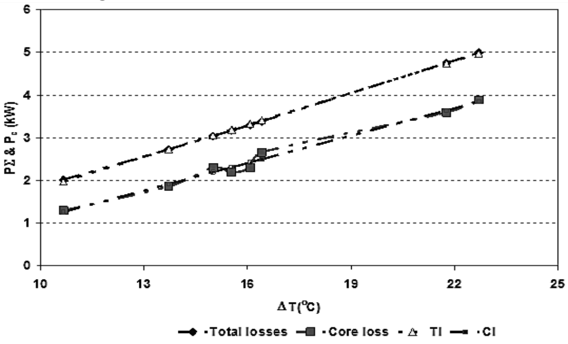


Figure 1. The power losses versus the temperature rise

It is seen that the core and total losses linearly rose as the temperature rise increased. Based on this curve, the total power loss and the core loss output powers would increase as the temperature rise increased too, with the average of 0.25 kW/°C and 0.30 kW/°C respectively. Figure 2 shows the ouput power as function of temperature rise.

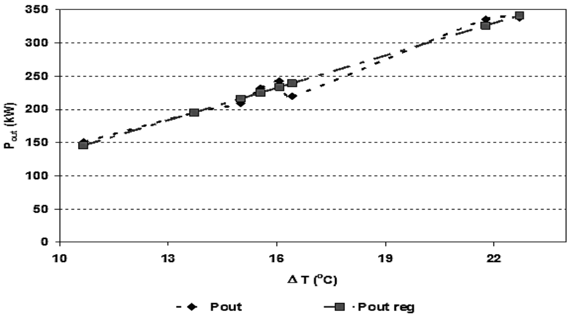


Figure 2. The calculated power output to the temperature rise

Both quantities would rise in proportional. The output power increased as the temperature rise rose, as 6.4 kW/°C. Table 1 lists the data of temperature rises, both measurement and calculation results.

Table 1. Calculation and measurement of themperature rise

Measurement results ΔT (°C)	Calculation results ΔT (°C)
24	10.66
23	15.00
19	21.76
19	22.70
22	13.72
21	15.54
21	16.07
22	16.41

The difference of the temperature rises between the calculation, and the measurement results were predicted to be caused by the less accurate of reading on the thermometer when the retrieval of data and it took a time for reading the thermometer.

From the calculations those have been done, the efficiencies of transformer depended on the transformer power output, so that when the output power increased, then the temperature rise and the efficiency decreased. Therefore, it was obtained the graph of efficiency against the temperature rise (ΔT), as shown in Figure 3.

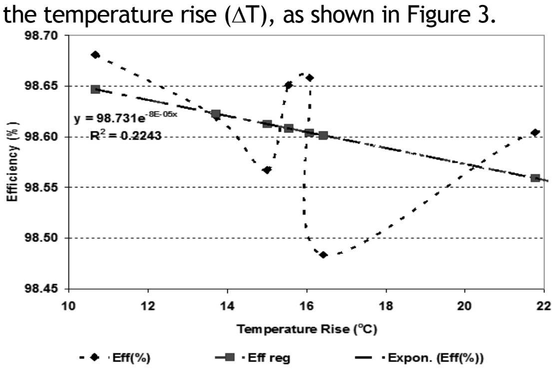


Figure 3. The efficiency to the temperature rise

The increasing temperature rise made the transformer efficiency fairly reduced. The efficiency would reduce as the temperature rise increased as the average of -6.41 %/°C.

Table 2 lists the sample of measurement results.

Table 2. Sample of measurement results

No	Time	Voltage (Volt)	Current (A) I_R	I_S	I_T	Average Current (A)	Cos ϕ	ΔT (°C)
1	08.00	300	400	417	410	409.0	0.71	24
2	09.00	400	420	410	410	413.3	0.73	23
3	10.00	500	500	550	500	516.7	0.75	19
4	11.00	520	510	500	510	506.7	0.74	19
5	12.00	360	410	450	480	446.7	0.70	22
6	13.00	390	450	500	480	476.7	0.72	21
7	14.00	400	430	510	500	480.0	0.73	21
8	15.00	430	400	400	430	410.0	0.72	22

Nevertheless, the average current values were based on the three phase of currents. It is shown that the voltage, current and power factor changed on every hour measurement. Nevertheless, generally, the temperature rises would increase as the load currents rose.

Table 3 lists the calculation samples of current and powers.

Table 3. Sample of calculation results

S_{rat} (kVA)	Current (A) I_R	I_S	I_T	Average Current (A)	$P_{k1\phi}=K_{1\phi}.I^2$ $P_{k1\phi R}$	$P_{k1\phi s}$	$P_{k1\phi T}$	$P_{k3\phi R}$ (W)	$P_0=\frac{V^2}{R_i}$ (W)
300	400	417	410	409.0	230.4	250.4	242.1	722.9	1293.9
400	420	410	410	413.3	254.0	242.1	242.1	738.1	2300.2
500	500	550	500	516.7	360.0	435.6	360.0	1155.6	3594.0
520	510	500	510	506.7	374.5	360.0	374.5	1109.1	3887.3
360	410	450	480	446.7	242.1	291.6	331.8	865.4	1863.1
390	450	500	480	476.7	291.6	360.0	331.8	983.4	2186.6
400	430	510	500	480.0	266.3	374.5	360.0	1000.8	2300.2
430	400	400	430	410.0	230.4	230.4	266.3	727.1	2658.1

Generally, the powers would increase as the currents rose. Table 4 lists the calculation samples of power, efficiency and temperature rise calculation results.

Table 4. Sample of power, efficiency and temperature rise calculation results

$P\Sigma = P_o + P_k$ (W)	$P_{out1\phi} = \frac{V}{\sqrt{3}}.I.\cos\phi$ (kWatt)			$P_{out\,3\phi}$ (Watt)	$P_{in} = P_o+P_k+P_{out}$ (Watt)	η (%)	$\Delta T = \left(\frac{P\Sigma}{At}\right)^{0.833}$ (°C)
	$P_{out\text{-}R}$	$P_{out\text{-}S}$	$P_{out\text{-}T}$				
2016.7	49.2	51.3	50.4	150.9	152.9	98.68	10.66
3038.3	70.8	69.1	69.1	209.0	212.1	98.57	15.00
4749.6	108.3	119.1	108.3	335.6	340.3	98.60	21.76
4996.4	113.3	111.1	113.3	337.7	342.7	98.54	22.70
2728.6	59.7	65.5	69.8	195.0	197.7	98.62	13.72
3170.0	73.0	81.1	77.8	231.8	235.0	98.65	15.54
3301.0	72.5	86.0	84.3	242.8	246.1	98.66	16.07
3385.2	71.5	71.5	76.9	219.9	223.2	98.48	16.41

Based on figures 4-7, the output powers would rise quadratically as the loading currents rose.

Figure 4 shows the phase-R power output versus the current magnitude. Generally, the output power would increase quadratically as the loading current rose.

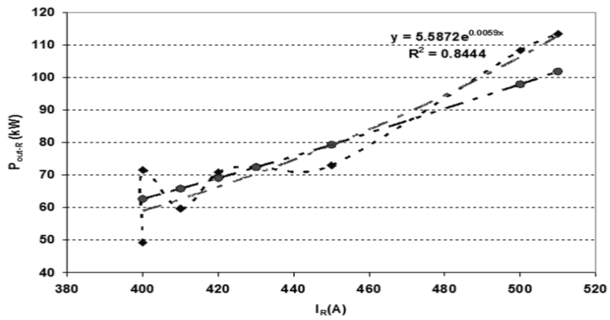


Figure 4. The phase-R power output to the current magnitude

Figure 5 shows the phase-S power output versus the current magnitude. Generally, the output power would increase quadratically as the loading current rose.

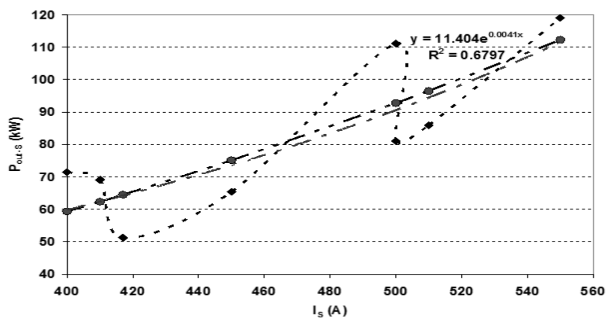


Figure 5. The phase-S power output to the current magnitude

Figure 6 shows the phase-T power output versus the current magnitude. Generally, the output power would increase quadratically as the loading current rose.

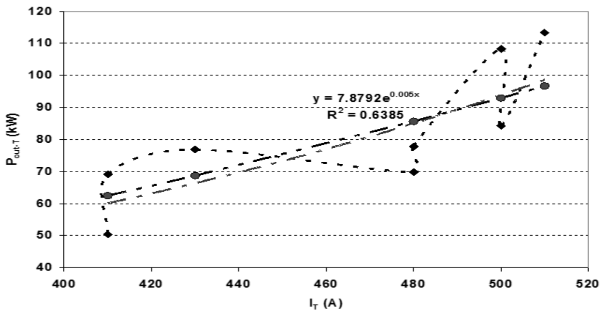


Figure 6. The phase-T power output to the current magnitude

Figure 7 shows the total power output to the average current magnitude.

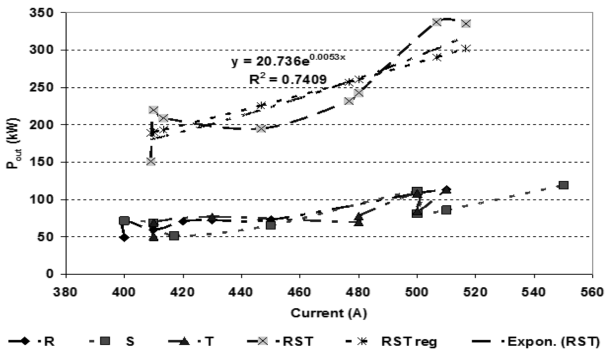


Figure 7. The total power output to the current magnitude

Figure 8 shows the efficiency versus the average current magnitude on three phase.

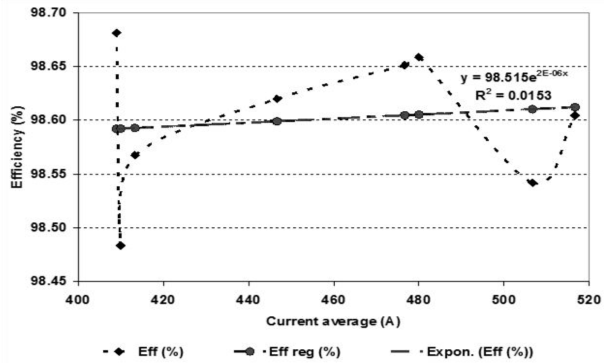


Figure 8. The efficiency to the current magnitude

Figure 9 shows the temperature rise versus the average current magnitude on three phase. The temperature rise would increase quadratically as the current rose.

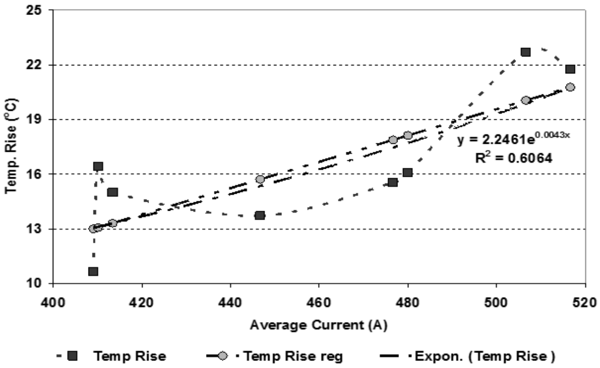


Figure 9. The temperature rise to the current magnitude

Figure 10 shows the core and total losses versus the average current magnitude on three phase.

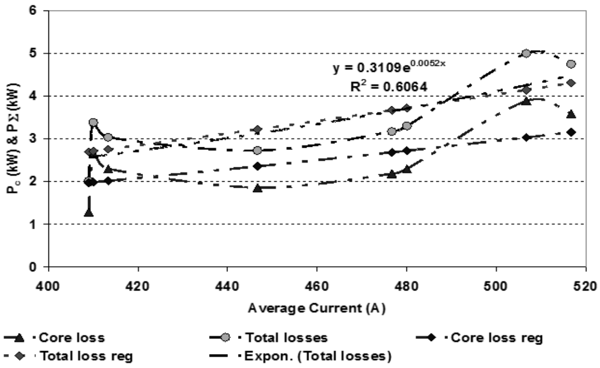


Figure 10. The core and total losses to the current magnitude

Figure 11 shows the correlation between the losses against the output power in linear.

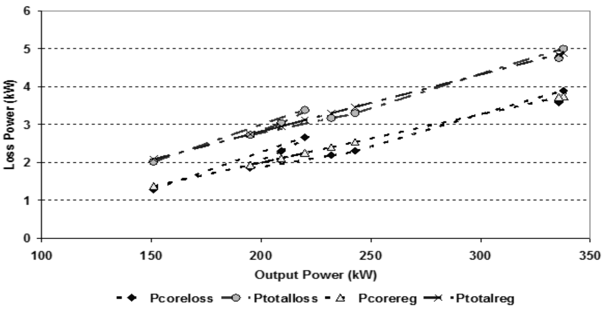


Figure 11. The core and total losses versus the output power

4. Discussion

Figure 1 indicates that the core and total losses were linier to the temperature rise, where the temperature rise increase as the loss as the losses increased too. For this case, the empirical equations are $P_c(kW)=0.214(\Delta T)-1.02$ and $P\Sigma(kW)=0.249-0.686$ for the core and total losses respectively. If these equations were be reversed, the become $(\Delta T) = 4.67\ P_c(kW)+4.766$ and $T=4.016P_\Sigma+2.755$ respectively for core and total losses.

Thus, the temperature rise is strongly depending on the core and total losses, more than four times.

Figure 2 shows the relation chart between the output power and the temperature rise, as the empirical regressive equation is $P_{out}(kW)=16.25(\Delta T)-27.52$ or in reverse $T=0.962P_{out}(kW)+1.694$. Base on this equation, the temperature rise was slightly influenced by the load. Thus, the temperature rise was dominantly influenced by the losses rather than the loading. However, both losses were tightly depending on the output power.

Figure 3 shows that the efficiency would reduce as the temperature rise increased. In the exponential, the relation is $\eta(\%)=98.7e^{-0.00008(\Delta T)}$ or in the linear, the relation is $\eta(\%)=-0.0079(\Delta T)+98.7$. Thus, the temperature rise would determine the efficiency considerably.

Figure 4 shows the correlation of phase-R output power against phase-R loading current, as $P_R(kW)=0.39I^2$ or $P_R(kW)=5.587e^{0.0059I}$.

Figure 5 shows the correlation of phase-S output power against phase-S loading current, as $P_S(kW)=0.37I^2$ or $P_S(kW) = 11.4e^{0.0041I}$. Figure 6 shows the correlation of phase-T output power against phase-T loading current, as $P_T(kW) = 0.37I^2$ or $P_T(kW)=7.88e^{0.005I}$.

While, Figure 7 shows the chart of correlation the total power versus the three-phase average current. The correlation is $P_T(kW)=0.00113I^2$ or $P_T(kW)=20.7e^{0.0053I}$. Based on these correlations, they show quadratically behaviour. However, they are with small constants, tend to be linear.

Figure 8 indicates the correlation of efficiency versus the average current. Based on these data, the efficiency would increase slightly as the average current increased. This correlation is $\eta(\%) = 0.0001875I_{av} + 98.5$ or $\eta(\%)=98.5e^{2E\text{-}6I}$.

Figure 9 shows the chart of temperature rise against the average current. The correlation tent to be linear. In the exponential, the correlation is $\Delta T(^oC)=2.246e^{0.0043I}$ or in linear, it is $\Delta T(^oC)=0.072I-16.5$.

Figure 10 shows the chart of core and total losses against the average current. The correlation tent to be quadratic. In the quadratic equations, the correlations are $P_o(kW)=0.000012I^2$ and $P\Sigma(kW)=0.000016I^2$ respectively for the core and total losses.

In figure 11, the regression is $P_{coreloss} = 0.01267P_{out}-0.53$, or reverse it is $P_{out}=78.92P_{core}+41.825$. On the other hand, $P_{totalloss}=0.015P_{out}-0.18$, reverse it is $P_{out}=66.64P_{totalloss}+12$. Thus, the output power tightly depended on the core and total losses.

Based on above figures, the linear graphics were the core and total losses versus the temperature rise, the output power versus the temperature rise and the loss power versus the output power. Therefore, it is said the losses, the output power and the temperature rise were closely correlated. Thus, the temperature rise was dominantly caused by the losses, rather than the loading power. Nevertheless, the power losses were significantly depending on the loading power.

5. Conclusions

From the yielded calculations, the temperature rise were obtained for power ouput on the transformer. The greater the total power losses, the greater the temperature rise. Nevertheless, it was depending on the power output of transformer.

The temperature rise largely increased, the transformer could lead to decline the transformer performance, that by indicated smaller of the transformer efficiency. The temperature rise was dominantly caused by the power losses, rather than the loading power. Indeed, the power losses were significantly depending on the loading power.

6. References

[1] Haritha, V.V.S.S., Ramamoorty, M., Jain, A., Thermal Modeling of Electrical Utility Transformers, Dissertation, the degree of Master of Science (by Research), International Institute of Information Technology Hyderabad, India, November 2011, pp.1-87.

[2] Ling, P.J.A., Eng, P., Transformers and Associated Losses - The Opportunity for Savings, www.powersmiths.com, accessed on June 27th, 2016. pp. 1-9.

[3] Liu, H.S., Ma, L., Gu, Y.T., Nielsen, S., Numerical investigation of mechanical and thermal dynamic properties of the industrial transformer, International Journal of Computational Methods (IJCM), 11(Supp 1), p. 1344012, 2014 World Scientific Publishing Company, pp.1-7.

[4] Azizi, D., Gholami, A., Azizi, D., Hot Spot Temperature Analysis in 3 Phase Transformers Using FEM Method, International Journal of Modern Engineering Research (IJMER), ISSN: 2249-6645, Vol.1, Issue.2, pp-425-429.

[5] Taghikhani, M.A., Modeling of Heat Transfer in Layer-Type Power Transformer, Przeglad Elektrotechniczny (Electrical Review), ISSN 0033-2097, R. 87 NR 12a/2011, pp.121-123.

[6] Firouzifar, S., Mahmoudi, J., Assessment of Power Transformer cooler with FEMLAB, www.ep.liu.se/ecp/027/019/ecp072719.pdf, accessed on July 1, 2016, pp. 159-165.

[7] Tenbohlen, S., Stirl, T., Stach, M., Assessment of Overload Capacity of Power Transformers by On-line Monitoring Systems, IEEE Power Engineering Society Winter Meeting, Columbus, Ohio, 2001. pp. 1-6.

[8] Guo, W., Wijaya, J., Martin, D., Lelekakis, N., Transformer winding temperature estimation based on tank surface temperature, Proc. SPIE 7981, Sensors and Smart Structures Technologies for Civil, Mechanical, and Aerospace Systems 2011, 79812Y (14 April 2011), pp.1-9.

[9] Olivares-Galvan, J. C., Escarela-Perez, R., Georgilakis, P.S., Fofana, I., Adame, S.M., A Bibliographic Analysis of Transformer Literature 1990-2000, Electrical and Electronic Engineering 2012, 2(3, 2012 Scientific & Academic Publishing, pp.96-121.

[10] Pinkienwicz, I., Kazmierski, M., Olech W., Malinowski, J., Sobocki, R., On-Site Processing of Insulation System of Large Power Transformers and Hot-Spot Computer Determination, CIGRÉ, Session 2004, A2-208, pp.1-8.

[11] Taghikhani, M.A., Power Transformer Winding Thermal Analysis Considering Load Conditions and Type of Oil, International Journal of Material and Mechanical Engineering Vol. 1 Iss. 6, November 2012, pp. 108-113.

[12] Gouda, O.E., Amer, G.M., Salem, W. A.A., Predicting transformer temperature rise and loss of life in the presence of harmonic load currents, Ain Shams Engineering Journal (2012) 3, 2090-4479, pp. 113–121.

[13] Bérubé, J.N., McDermid, J.A.W., Transformer Winding Hot Spot Temperature Determination (Nov. 2006), www.qualitrolcorp.com/ uploadedFiles/ Siteroot/ Products.

[14] Radakovic, Z., Feser, K., A New Method for the Calculation of the Hot-Spot Temperature in Power Transformers with ONAN Cooling, IEEE Transactions On Power Delivery, Vol. 18, No. 4, October 2003, pp. 1284-1292.

[15] Susa, D., Dynamic Thermal Modelling of Power Transformers, Doctoral Dissertation, Power Systems and High Voltage Engineering, Department of Electrical and Communications Engineering, Helsinki University of Technology, 2005.

[16] Taghikhani, M.A., Gholami, A., Estimation of Hottest Spot Temperature in Power Transformer Windings with NDOF and DOF Cooling, Transactions D: Computer Science & Engineering and Electrical Engineering Vol. 16, No. 2, pp. 163{170, Sharif University of Technology, December 2009, Research Note.

[17] Taghikhani, M.A., Power Transformer Winding Thermal Analysis Considering Load Conditions and Type of Oil, International Journal of Material and Mechanical Engineering Vol. 1 Iss. 6, November 2012, pp. 108-113.

[18] Reddy, A.S., Vijaykumar, M., Hottest Spot and Life Evaluation of Power Transformer Design Using Finite Element Method, Journal of Theoretical and Applied Information Technology, 2005 - 2008 JATIT, pp.238-243.

[19] Georgilakis, P.S., Spotlight on Modern Power Transformer Design, 2 Conventional Transformer Design, http://www.springer.com/978-1-84882-666-3, pp.45-122.

[20] Taghikhani, M.A., Power Transformer Top Oil Temperature Estimation with GA and PSO Methods, Energy and Power Engineering, 2012, 4, pp.41-46.

[21] Suryasen, K., Devadas, K.V., Harish A., GUI based Testing Tool for Transformer International Journal of Electrical and Computer Engineering (IJECE), Vol. 4, No. 3, June 2014, ISSN: 2088-8708, pp. 359-365.

[22] Radaković, Z., Numerical determination of characteristic temperatures in directly loaded power oil transformer, European Transactions on Electrical Power, Vol. 13, No. 1, pp. 47-54, Jan. 2003.

[23] Hashmi, M., Lehtonen, M., Hänninen, S., Effect of Climate Change on Transformers Loading Conditions in the Future Smart Grid Environment, Open Journal of Applied Sciences, 2013, 3, 24-29, pp.24-29.

[24] Wittmaack, R., Thermal Design of Power Transformers via CFD, Journal of Energy and Power Engineering 9 (2015), David Publishing, pp.102-107.

[25] Olivares-Galván, J.C., Escarela-Pérez, R., Georgilakis, P.S., Campero-Littlewood, E., Separation of No-Load Losses for Distribution Transformers Using Experimental Methods: Two Frequencies and Two Temperatures, 7th Mediterranean Conference on Power Generation, Transmission, Distribution and Energy Conversion, Medpower 2010, Agia Napa, Cyprus, 7-10 November 2010, pp.1-5.

[26] Kulkarni, S.V., Khaparde, S.A., Transformer Engineering, Design and Practice, Marcel Dekker, Inc., New York, U.S.A., ISBN: 0-8247-5653-3, 2004, pp.127-230.

[27] Radakovic, Z., Tenbohlen, S., Thermal model of oil power transformers with a tap changer, Turkish Journal of Electrical Engineering & Computer Sciences, Turk J Elec Eng & Comp Sci (2016) 24: 3293-3308, pp. 3293- 3308.

[28] Hunt, R.M.S., Michael L., Giordano, B.S., Thermal Overload Protection of Power Transformers-Operating Theory and Practical Experience, 59th Annual Protective Relaying Conference Georgia Tech Atlanta, Georgia April 27th-29th, 2005, pp.1-31.

[29] Kori, A.K., Sharma, A.K., Bhadoriya, A.K.S., Intelligent Diagnostic Method for Ageing Analysis of Transformer, Energy and Power Engineering, , 4, March 2012, pp.53-58.

[30] Duarte, D., Aspects of Transformer Fires in Brazil, Open Journal of Safety Science and Technology, September 2012, 2, pp.63-74.

[31] Mousavi, S.A., Electromagnetic Modelling of Power Transformers for Study and Mitigation of Effects of GICs, Doctoral Thesis, Royal Institute of Technology (KTH) School of Electrical Engineering, Division of Electromagnetic Engineering, Stockholm, Sweden 2015, pp.184-187.

[32] Zhang, M., Daniel, J., Tylavsky, Ayyanar, R., Holbert, K., Dynamic Loading of Substation Distribution Transformers: An Application for use in a Production Grade Environment, Thesis for the Degree Master of Science, Arizona State University, December 2013, pp.1-72.

[33] Garduno, H., Chen, P., Bergstrom, T., Temperature Rise Testing of Current Transformers: Improvement in Test Method, Master Thesis Report, Division of Electric Power Engineering, Department of Energy and Environment, Chalmers University of Technology, Göteborg, Sweden

2012, pp.1-37.

[34] Roizman, O., Davydov, V., Temperature Rise Tests, Centre for Power Transformer Monitoring, Diagnostics and Life Management (transformer LIFE) Monash University, Spring 2009 IEEE Transformers Committee Meeting Miami FL, 21 April 2009, Australia.

[35] M.T. Ishak, Q. Zhong, Z.D. Wang, Impact of Load Profiles, WTI Setting and Hotspot Factors on Loss-of-Life of Dual Cooling Mode Transformers, Proceedings of the 16th International Symposium on High Voltage Engineering Copyright °c 2009 SAIEE, Innes House, Johannesburg, ISBN 978-0-620-44584-9, Paper F-31, pp. 1-5.

[36] Sen, P.K., Pansuwan, S., Malmedal, K., Martinoo, O., Simoes, M.G., Butler-Purry, K., Transformer Overloading and Assessment of Loss-of-Life for Liquid-Filled Transformers, Power Systems Engineering Research Center, PSERC Publication 11-02, February 2011.

[37] Eckholz, K., Knorr, W., Schäfer, M., Feser, K., Cardillo, E., New Development in Transformer Cooling Calculations, www.uni-stuttgart.de/ ieh/ forschung/veroeffenttichungen/2004_cigre_eckholz.pdf

[38] Saad, F. A. M., Predicting Transformer end of Life Using Transformer Thermal Life Simulation Technique, Thesis of the degree of Master of Electrical Engineering, Faculty of Electrical and Electronics Engineering, University Tun Hussein Onn Malaysia (UTHM), April 2011.

[39] Gupta, A., Singh, R., Computation of Transformer Losses under the Effects of Non-Sinusoidal Currents, Advanced Computing: An International Journal (ACIJ), Vol.2, No.6, November 2011, pp.91-104.

[40] Harlow, J.H., Electric Power Transformer Engineering, CRC Press LLC, 2004.

[41] Madzarevic, V., Kapetanovic, I., Tesanovic, M., Kasumovic, M., Recent Researches in Energy & Environment, ISBN: 978-960-474-274-5, pp. 353-358.

[42] Z. Radakovic, Numerical Determination of Characteristic Temperatures in Directly Loaded Power Oil Transformer, ETEP Vol. 13, No. 1, January/February 2003, pp.1-8.

[43] Radakovic, Z., Cardillo, E., Feser, K., The influence of transformer loading to the ageing of the oil-paper insulation, XIIIth International Symposium on High Voltage Engineering, Rotterdam, Netherlands, 2003, ISBN: 90-77017-79-8, pp.1-4.

[44] Perez, J., Fundamental principles of transformer thermal loading and protection, Protective Relay Engineers, 2010 63rd Annual Conference for, College Station, TX, March 29 2010-April 1 2010, ISBN: 978-1-4244-6073-1, pp.1-14.

[45] Ţălu, M., Ţălu Ş., Analysis of Heat Exchanger Efficiency for an Electric Power Transformer, The Scientific Bulletin of Valahia University-Materials and Mechanics-Nr. 6 (year 9) 2011, pp. 220-223.

[46] Radakovic, Z., Cardillo, E., Feser, K., Temperature Distribution in Windings of Transformers with natural Oil circulation, www.uni-stuttgart.de/ieh/forschung /veroeffentlichungen/2002_icem_radakovic.pdf, pp.1-6.

[47] Jiao, Y., CFD Study On The Thermal Performance of Transformer Disc Windings Without Oil Guides, Master of Science Thesis, KTH School of Industrial Engineering and Management Energy Technology, EGI-2012-089MSC, EKV915, Division of ETT, SE-100 44 Stockholm.

[48] Pradhan, M.K., Ramu, T.S., Estimation of the Hottest Spot Temperature (HST) in Power Transformers Considering Thermal Inhomogeniety of the Windings, IEEE Transactions on Power Delivery, Vol. 19, No. 4, October 2004, pp. 1704-1712.

[49] Dofan, J.A.A.R., Study on Thermal Model For Calculating Transformer Hot Spot Temperature, Thesis of the degree of Master of Electrical & Electronic Engineering, Faculty of Electrical & Electronic Engineering, University Tun Hussein Onn Malaysia (UTHM), May 2011.

[50] Babak, D.H.A. Milani, K.A.T.K.R., Calculation of Mechanical Stresses in Hermetically Sealed Transformers, 19th International Conference on Electricity Distribution, CIRED2007 Session 1, Vienna, 21-24 May 2007, Paper No 0309, pp.1-6.

[51] Ţalu, Ş.D.L., Ţalu, M.D.L., Dimensional Optimization of Frontal Radiators of Cooling System for Power Transformer 630 kVA 20/0.4 kV in Terms of Maximum Heat Transfer, U.P.B. Sci. Bull., Series C, Vol. 72, Iss. 4, 2010, ISSN 1454-234x, pp.249-260.

[52] Godina, R., Rodrigues, E.M.G., Matias, J.C.O., Catalão, J.P.S., Effect of Loads and Other Key Factors on Oil-Transformer Ageing: Sustainability Benefits and Challenges, Energies 2015, 8, ISSN 1996-1073, pp. 12147-12186.

[53] Joshi, K.U., Deshmukh, N. K., Thermal analysis of oil cooled transformer, CIGRÉ, Session 2004, A2-101, pp.1-9.

[54] Popescu, M.C., Modelling and Simulations of Oil-filled Transformer Loss-of-Life Models, WSEAS Transactions on Circuits and Systems, Issue 10, Volume 8, October 2009, ISSN: 1109-2734, pp. 801-810.

[55] Popescu, M.C., Bulucea, A., Perescu, L., Improved Transformer Thermal Models, WSEAS Transactions on Heat and Mass Transfer, Issue 4, Volume 4, October 2009, ISSN: 1790-5044, pp. 87-97.

[56] Martin, D., Wijaya, J., Lelekakis, N., Susa, D., Heyward, N., Thermal Analysis of Two Transformers Filled with Different Oils, IEEE Electrical Insulation Magazine, January/February — Vol. 30, No. 1, 2014, 0883-7554/12/$31/©2014/IEEE, pp.39-45.

[57] Behjat, V., A Coupled Thermal-Electromagnetic FEM Model to Characterize the Thermal Behaviour of Power Transformers Damaged By Short Circuit Faults, International Journal of Electrical Energy, Vol. 1, No. 4, December 2013, Engineering and Technology Publishing, pp. 194-200.

[58] Gao, Y., Azis, N., Wang, Z.D., Jones, D., Impact of Electric Vehicles on the Thermal Performance of 11 kV Distribution Transformers, https://www.researchgate.net/ publication, access on 29th June 2016, pp.1-16.

[59] Swift, G. W., Zocholl, S. E., Bajpai, M., Burger, J. F., Castro, C. H., Chano, S. R., Cobelo, F., de Sá, P., Fennell, E. C., Gilbert, J.G., Grier, S.E., Haas, R.W., Hartmann, W. G., Hedding, R.A., Kerrigan, P., Mazumdar, S., Miller, D.H., Mysore, P.G., Nagpal, M., Rebbapragada, R.V., Thaden, M.V., Uchiyama, J.T., Usman, S.M., Wardlow, J.D., Yalla, M., Adaptive Transformer Thermal Overload Protection, IEEE Transactions on Power Delivery, Vol. 16, NO. 4, October 2001, pp. 516-521.

[60] Marko, R.M., Thermal Modelling of a Natural-Convection-Cooled, Oil-Immersed Distribution Transformer, Thesis Master of Science, Mechanical Engineering, University of Manitoba, Winnipeg, Manitoba, Canada, 1997, pp.204-206.

[61] Susa, D., Nordman, H., A Simple Model for Calculating Transformer Hot-Spot Temperature, IEEE Transactions on Power Delivery, Vol. 24, NO. 3, July 2009, 0885-8977, pp. 1257-1265.

[62] Campos, A.R.T., Simulation of a distribution transformer, WSEAS Transactions on Fluid Mechanics, Issue 3, Volume 7, July 2012, E-ISSN: 2224-347X, pp. 106-115.

[63] Taghikhani, M.A., ONAN Power Transformer Heat Transfer Modeling, International Journal of Energy Science, IJES Vol.1 No.3 2011, World Academic Publishing, PP.176-179.

[64] Radakovic, Z., Maksimovic, S., Non-stationary thermal model of indoor transformer stations, Electrical Engineering 84 (2002), Springer-Verlag 2002, pp. 109–117.

[65] Radakovi, Z., Kali, Dj., Results of a novel algorithm for the calculation of the characteristic temperatures in power oil transformers, Electrical Engineering 80 (1997) 2o5-214 _9 Springer-Verlag 1997, pp. 205-214.

[66] Alexander, D. Hilshey, P.D., Hines, H., Dowds, J.R., Estimating the acceleration of transformer aging due to electric vehicle charging, 2011 IEEE Power and Energy Society General Meeting, 24-29 July 2011, San Diego, CA, ISSN: 1932-5517, E-ISBN: 978-1-4577-1001-8, IEEE, pp.1-9.

[67] Askari, M.T., Kadir, M.Z.A.Ab., Izadi, M., On the Trend of Improvement of Thermal Model for Calculating the TOT

and HST, Przeglad Elektrotechniczny, ISSN 0033-2097, R. 88 NR 12a/2012, pp. 297-301.

[68] Rosenlind, J., Lifetime Modeling and Management of Transformers, Doctoral Thesis KTH Royal Institute of Technology School of Electrical Engineering Division of Electromagnetic Engineering Stockholm, Sweden 2013, Trita-EE 2013:037, ISBN 978-91-7501-883-6, pp.1-51.

[69] Ishak, M.T., Zhong, Q., Wang, Z.D., Impact of Load Profiles, WTI Settings and Hotspot Factors on Loss-of-Life of Dual Cooling Mode Transformers, Proceedings of the 16th International Symposium on High Voltage Engineering, SAIEE 2009, Innes House, Johannesburg, ISBN 978-0-620-44584-9, F-31, pp.1-5.

[70] Sen, P.K., Pansuwan, S., Malmedal, K., Martinoo, O., Simoes, M.G., Butler-Purry, K., Transformer Overloading and Assessment of Loss-of-Life for Liquid-Filled Transformers, Final Project Report, PSERC Publication 11-02, February 2011, pp.1-106.

[71] Bicen, Y., Çilliyuz, Y., Aras, F., Aydugan, G., An Assessment on Aging Model of IEEE/IEC Standards for Natural and Mineral Oil-Immersed Transformer, 2011 IEEE International Conference on Dielectric Liquids, Trondheim, 26-30 June 2011, ISSN: 2153-3725, E-ISBN: 978-1-4244-7354-0, Print ISBN: 978-1-4244-7352-6, pp. 1-4.

[72] Popescu, M.C., Popescu, C., Transformer thermal and loss of life models, Full Length Research Paper, Journal of Electrical and Electronics Engineering Research Vol. 1 (1), pp. 001-022, Academic Journals, Nov. 2009, pp.1-22.

[73] Cardillo, E., Feser, K., New Approach in Thermal Monitoring of Large Power Transformers Applied on A 350 MVA ODAF-Cooled Unit, www.uni-stuttgart.de/ieh/forschung/.../2004_aptadm_cardillo.pdf, access 29th June 2016, pp.1-5.

[74] Said, D. M., Nor, K. M., Majid, M. S., Analysis of Distribution Transformer Losses and Life Expectancy using Measured Harmonic Data, Proceedings of 14th International Conference on Harmonics and Quality of Power-ICHQP 2010, 26-29 Sept. 2010, Bergamo, E-ISBN : 978-1-4244-7245-1, pp. 1-6.

[75] Jayasinghe, N.R, Lucas, J.R., Perera, K.B.I.M., Power System Harmonic Effects on Distribution Transformers and New Design Considerations for K Factor Transformers, IEE Sri Lanka Annual Sessions-September 2003, pp.1-7.

[76] Orenchak, G., Predicting Temperature Rise of Ferrite Cored Transformers, www.tscinternational.com /predicttemp.pdf, accessed in December 2017.

Acknowledgment

We would like to express the deepest appreciation to **PT DI** Indonesia, which has supported to provide the data.

Biography

Waluyo was born in Magelang, Central Java (Indonesia), on January 2, 1969.
He graduated Institut Teknologi Bandung (ITB), Department of Electrical Engineering in Bandung (Indonesia), in 1994.
He received the Master and PhD degrees in electrical engineering from the same university, in 2002 and 2010 respectively.
Now, he works as academic staff (lecturer) at Department of Electrical Engineering, Institut Teknologi Nasional Bandung (ITENAS). His research interests concern: high voltage engineering, transformer and power system transmission.
E-mail: waluyo@itenas.ac.id

Siti Saodah was born in Cimahi, West Java, (Indonesia), on November 27th, 1977.
She graduated Institut Teknologi Nasional Bandung (ITENAS), Department of Electrical Engineering in Bandung (Indonesia), in 2001.
She received the Master degree in electrical engineering from Institut Teknologi Bandung (ITB), in 2006. Now, she works as academic staff (lecturer) at Department of Energy Conversion, Politeknik Negeri Bandung (Polban). Her research interests concern: high voltage engineering, transformer and electric machines.
E-mail: siti@polban.ac.id

Rohana was born in Kuningan, West Java (Indonesia), on August 3, 1992.
He is senior university student and conducting a final project at Department of Electrical Engineering, Institut Teknologi Nasional Bandung (ITENAS), in Bandung, Indonesia.
His research interests concern: high voltage engineering and transformer.
E-mail: rohanacau@gmail.com

EEA fondată în 1950
ELECTROTEHNICĂ, ELECTRONICĂ, AUTOMATICĂ

Publicaţie trimestrială a ICPE

ISSN 1582-5175

Societatea Ştiinţifică ICPE

(Scientific Society of ICPE)
www.icpe.ro/en/p/1_12_Icpe_scientific_society

Scientific Society of ICPE aims to:
- promote the reputation and the success of the omanian scientific research in electrical ngineering and other related or interdisciplinary ields;
- support the creation, the innovation and the cientific research (fundamental, applied, uantitative, qualitative, results-oriented, etc.) and e trans-disciplinary and inter-disciplinary esearch;
- encourage and promote the continuing ofessional training of its members in the various ecialties of the electrical engineering;
- to support the young specialists for their professional training or specialization;
- to develop the bi- and multi-lateral scientific collaboration with specialists in engineering sciences and/or other related or interdisciplinary fields working in research centres and universities in Romania and abroad;
- to develop and promote the "clean" technologies by programmes and projects in the field of environmental sustainable development;
- to support the national and international scientific events, seminars, conferences and other meetings specialized in the field of electrical engineering.