UNIVERSITATEA POLITEHNICA TIMIŞOARA

Manuela PĂNOIU

Research-based modeling, simulation and intelligent techniques in electrical engineering

Habilitation Thesis

2015

Cuprins

1. SUMMARY

1.1. ABSTRACT

The habilitation thesis summarizes the research and the results obtained by the candidate after receiving her doctoral degree at Polytechnic University of Timisoara, confirmed by the *Ministerial Order no. 5285 of December 28, 2001.*

Due to the fact that the candidate was in the past a part of a multidisciplinary research team and still is in present as well and also due to the fact that she graduated the specialization Automation and Computer Science and the field in which she obtained her Ph.D. is Electrical Engineering, the candidate has been assimilated interdisciplinary skills. Thus, these skills allowed her to develop research in three main areas:

- Modeling, simulation and identification applied in electrical engineering and in other fields as well;
- Artificial and computational intelligence applied in electrical engineering and in other fields;
- Contributions on developing of interactive educational software

The majority of the candidate research activitivity is concentrated on the first two research areas. These two research areas are not totally independent of one another. Much of the candidate's research fits into two or in all three research areas. It can be said that within the first two research areas, the candidate continued, at least partially, her doctoral thesis research, but new research topics were also addressed. The third research direction was developed by the candidate from the desired to bring some contributions to the educational field by implementing educational applications that are using in laboratory and as well in the course activity.

The habilitation thesis summarizes the candidate research, especially within the first two research areas, with specific references to publications resulting from this research. Some of her published papers are the results of research projects in which the candidate was either project manager or team leader or part of the research team.

The habilitation thesis is divided into three parts. After a brief introduction, presented in chapter 1, Chapter 2 is following, this one being the most extended chapter, which presents the results of the candidate research with specific references to publications, especially the ones indexed in ISI Web of Knowledge and in other international databases, but in other publications as well. Chapter 3 presents a proposal for the development of the candidate future academic career.

Chapter 2 contains technical presentation of the research results and it is also structured into four parts.

The first part contains an overview of the research activities and the obtained results during 2002 – 2015 periods that followed after receiving by the candidate the doctor engineer title. This part summarizes the results of the research conducted by the candidate during this period. The candidate has published over 130 papers of which 41 are indexed in the ISI Web of Knowledge database. From these 41 papers, the candidate is the first author in 13 of them. A number of 73 of the candidate papers are indexed in other international databases, especially Scopus, Engineering Village 2, IEEExplore, ACM, Inspec and Google Scholar. Some published papers by the candidate have been cited, so the candidate has 28 ISI Web of Knowledge citations and 77 citations in other international databases. This part also presents the projects in which the candidate has participated, either as project manager or as a team leader or team member. The journals and conferences to which the candidate was a reviewer and a member of the international committee of the program are also presented. The candidate has been invited to 4 conferences as a plenary speaker, one of them was ISI Web of Knowledge indexed, and 2 were indexed in international databases and another one in a national conference. At the final of this part, a review of the management and organizational skills of the candidate was made, with specific references to the positions held by the candidate during each period.

The second part of the technical presentation contains a detailed presentation of the candidate research contributions in the field of modelling, simulation and control of some processes from electrical engineering. This area of research is a continuation of the research conducted by the candidate after obtaining her PhD. doctoral thesis. Specifically, the candidate has studied the modelling of the electric arc in the electric arc furnace installation. The first paragraph presents some new electric arc models which candidate has studied. All simulations accomplished with these models are compared with experimental measurements. In this paragraph, simulations of the entire system of the electric arc furnace were also presented. Based on these simulations, solutions for active power control and for positioning the electrodes were proposed. The flicker effect, which is widespread in the case of high power electric arc furnaces, was also simulated. Many of the presented papers in this paragraph are the result of a project obtained after winning a competition, project on which the candidate was the project manager. This paragraph ends with presentation of other modelling and simulation-based researches, in which the candidate participated as co-author.

The third part of the technical presentation contains the candidate contribution in artificial intelligence field, especially in computational intelligence applied in Electrical Enginnering and also in other engineering fields. This is the main area in which the candidate has conducted research lately. At the beginning of the third part, some of the results of modelling the electric arc using neural networks are presented, these being continuing her PhD research. Then, a neuro-fuzzy system used to predict the current in the electric arc is presented. This is followed by the presentation of some researches regarding the implementation of systems based on fuzzy logic using digital signal processors. In this part, the candidate contribution to the programming of signal processors in a system based on fuzzy logic, was presented, research implemented with the use of a TMS 320 series signal processor. There are two such systems to which the candidate has contributed, particularly to the fuzzy system programming. One of the applications was implemented as a result of a research contract with the economic environment. As in the previous case, the third part concludes with a presentation of other achievements in the artificial intelligence field by teams of which the candidate was a member, not necessarily as main researcher.

The fourth part summarizes some of the results obtained by the candidate as a member of a team that investigated the implementation of educational software systems. The team of which the candidate was member has implemented a series of practical educational systems that are used by the students as learning support. Those systems were implemented mostly in Java and can be included in an e-learning platform as a laboratory or course applications.

The last chapter, the third one, summarizes the candidate personal contributions and establishes a future development plan for the candidate.

1.2. REZUMAT

Teza de abilitare sintetizează activitatea de cercetare și rezultatele obținute de candidată după obţinerea titlului de doctor al Universităţii Politehnica Timişoara, confirmat prin *Ordinul de Ministru nr. 5285 din 28 decembrie 2001.*

Deoarece candidata a făcut și face parte în continuare dintr-un colectiv de cercetare multidisciplinar dar și datorită faptului că specializarea absolvită este Automatizări și Calculatoare, iar domeniul în care a obținut titlul de doctor este Inginerie Electrică, candidata a asimilat competențe interdisciplinare. Aceste competențe i-au permis să desfășoare activități de cercetare în trei direcții principale:

- Modelarea, simularea și identificarea sistemelor aplicate în domeniul Ingineriei Electrice, precum și în alte domenii;
- Inteligență artificială și computațională în Ingineria Electrică și alte domenii;
- Implementare de aplicații software cu caracter educational.

Marea majoritate a activității cercetării desfășurată de candidate se concentrează pe primele 2 direcții de cercetare. Aceste 2 direcții de cercetare nu sunt total independente una față de cealaltă. Multe dintre cercetările candidatei se încadrează în ambele direcții de cercetare. Se poate spune că în primele două direcții de cercetare, cel puțin parțial, candidata a continuat cercetări din perioada de doctorat, dar a abordat și tematici noi de cercetare.

Cea de-a treia direcție de cercetare a fost abordată de candidată din dorința de a aduce contribuții procesului didactic prin utilizare de programe software cu caracter educational, care sunt utilizate la activitățile de laborator cât și de curs.

Lucrarea de față prezintă succint rezultatele cercetărilor candidatei, în special în primele două direcții de cercetare, cu referiri concrete la publicațiile rezultate în urma acestor cercetări. O parte dintre lucrările publicate sunt rezultate ale unor granturi de cercetare la care candidata a fost director de grant sau responsabil de echipă a făcut parte din echipa de cercetare.

Teza de abilitare este structurată pe trei părți. După o scurtă introducere, prezentată în capitolul 1, urmează capitolul 2 cu cea mai mare întindere, care prezintă rezultatele cercetărilor cu referiri concrete la publicații, în special indexate în ISI Web of Knowledge și în alte baze de date internaționale, dar și în alte publicații. Capitolul 3 prezintă o propunere de dezvoltare a carierei universitare viitoare.

Capitolul 2 conține prezentarea tehnică a rezultatelor cercetărilor și este structurat la rândul său în patru părți.

Prima parte conține o trecere în revistă a activității de cercetare și a rezultatelor obținute în perioada 2002 – 2015, perioadă care a urmat după obținerea de către candidată a titlului de doctor inginer. Această parte sintetizează rezultatele cercetărilor făcute de candidată în perioada menționată.

Astfel, candidata are publicate peste 130 lucrări dintre care 41 sunt indexate în baza de date ISI Web of Knowledge. Dintre acestea 41, la 13 candidata este prim autor. Un număr de 73 dintre lucrările candidatei sunt indexate în alte baze de date internaționale, în special Scopus, Engineering Village 2, IEEExplore, ACM precum și Google Scholar. Unele dintre lucrările publicate de către candidată au fost citate, astfel candidata are 28 citări ISI Web of Knowledge și 77 în alte baze de date internaționale. Tot în această parte sunt prezentate și granturile la care candidata a participat fie în calitate de director de grant, fie ca coordonator de echipa de cercetare fie ca membru în echipă. Sunt prezentate de asemenea revistele și conferințele la care candidata a fost recenzor și membru în comitetul internațional de program. Candidata a fost invitată la 4 conferințe în calitate de plenary speaker, una dintre acestea fiind conferință indexată ISI Web of Knowledge, 2 indexate în baze de date internaționale și una într-o conferință națională. În finalul acestei părți a fost făcută o trecere în revistă a competențelor manageriale și organizatorice ale candidatei cu referiri concrete la pozițiile ocupate de candidată în perioada analizată.

Partea a doua din prezentarea tehnică conține o prezentare detaliată a contribuțiilor cercetărilor candidatei în domeniul modelării, simulării și controlului unor procese din ingineria electrică. Acest domeniu de cercetare este o continuare a cercetărilor făcute de candidată după obținerea titlului de doctor. Mai exact, în acest domeniu candidata a studiat modelarea arcului electric din componența instalației cuptoarelor trifazate cu arc electric și acțiune directă. Astfel, în primul subcapitol sunt prezentate unele noi modele ale arcului electric pe care candidata le-a studiat. Toate simulările făcute cu ajutorul acestor modele sunt comparate cu măsurători experimentale. Tot în acest subcapitol s-au prezentat simulări ale întregii instalații ale cuptorului cu arc electric. Pe baza acestor simulări au fost propuse soluții pentru controlul puterii active și pentru reglarea poziției electrozilor. În continuare a fost simulat efectul de flicker, foarte răspândit în cazul cuptoarelor cu arc electric de mare putere. O mare parte dintre lucrările prezentate în acest subcapitol au rezultat în urma unui grant câștigat prin competiție la care candidata a fost director de proiect. Acest subcapitol se încheie cu prezentarea altor cercetări bazate pe modelare și simulare la care candidata a participat în calitate de coautor.

Partea a treia din prezentarea tehnică prezintă contribuțiile candidatei în domeniul inteligenței artificiale, în special în cadrul inteligenței computaționale aplicate în special în Ingineria Electrică dar și în alte domenii inginerești. Acesta este principalul domeniu în care candidata a efectuat cercetări în ultima perioadă de timp. La începutul părții a treia se prezintă unele rezultate ale modelării arcului electric cu rețele neuronale, care sunt de asemenea continuări ale cercetărilor din perioada doctoratului. Apoi se prezintă un sistem neuro-fuzzy utilizat la predicția curentului în arcul electric. Urmează prezentarea unor cercetări cu privire la implementarea de sisteme bazate pe logica fuzzy cu ajutorul procesoarelor numerice de semnal. Aici este evidențiată contribuția candidatei la programarea procesoarelor de semnal în cadrul unui sistem bazat pe logica fuzzy realizat practic cu procesor de semnal din seria TMS 320. Sunt două astfel de sisteme la care candidata a contribuit în special la partea de programare a sistemului fuzzy. Una dintre aplicații s-a realizat practic, fiind un rezultat al unui contract de cercetare cu mediul economic. Ca și în cazul anterior, partea a treia se încheie cu prezentarea altor realizări din domeniul inteligenței artificiale realizate de echipe la care candidata a fost membră în echipă, nu neapărat ca cercetător principal.

Partea a patra prezintă foarte sumar câteva dintre rezultatele obținute de candidată ca membră a unei echipe care și-a propus implementarea unor sisteme informatice educaționale. Echipa din care a făcut parte candidata a realizat astfel de sisteme informatice educaționale ce se utilizează în activități didactice cu studenții ca elemente ajutătoare. Sistemele respective au fost implementate în mare parte în limbajul Java, ele putând fi incluse într-o platformă de e-learning ca aplicații pentru laborator sau curs.

Ultimul capitol, cel de-al treilea, sintetizează contribuțiile personale ale candidatei și definește un plan de dezvoltare viitoare al candidatei.

2. TECHNICAL PRESENTATION

Context of the habilitation

In the following habilitation thesis a summary of the research performed by the candidate over a period of almost 14 years is presented. This research work has been carried out during the years 2002–2015 in the Electrical Engineering and Industrial Informatics Department of the Polytechnic University of Timisoara, where the candidate have been working as a teaching and research staff member. This habilitation thesis shows the candidate's research between achieving her doctorate in October 2001 and 2015. An important part of the candidate's research is actually a continuation of what she had worked on during her PhD.

The candidate's PhD thesis was entitled "Simulation of some processes based on the modeling of three phase electric arc furnace" and was presented by the candidate at the Polytechnic University of Timişoara in 2001.

The beginning of the candidate's university career was in 1992, when the candidate has held the post of Assistant Professor in the Ecological University of Bucharest – Deva branch. Then in 1994 the candidate held the post of Assistant in the University Politehnica Timisoara.

Since the beginning of her university career, the candidate worked in a multidisciplinary team. She has been a member of the Department of Electromechanics since 1994, and by the reorganization of the departments she became a member of the Department of Electrotechnics (1996). During this period, namely in March 1994, she was admitted to the PhD program of the Faculty of Engineering of Hunedoara under the guidance of Prof. Anton Saimac. The PhD theme follow power quality issues, in Electric Arc Furnace domain, as a consequence of working in the field of Electrical Engineering. The theme chosen was consistent with the interests of the research team of the Faculty of Engineering of Hunedoara, which had, at the time, several research contracts with S.C. Siderurgica S.A. Hunedoara. Also, the theme was chosen taking into account the undergraduate fields of study which existed at the Engineering Faculty of Hunedoara at the time: Electromechanics, Technologic Machinery and Metallurgy. She passed her exams and scientific reports within the individual training session respecting the deadlines. But an unforeseen and unfortunate event occurred, namely the untimely death of Professor Anton Saimac, which led to the transfer of the candidate to Prof. Ioan Sora, at the Department of Electro-Energy of the Polytechnic University of Timisoara. The thesis retained the subject matter, but became more oriented towards modeling and simulation of nonlinear processes in the electric arc furnace. Thus the final title of the thesis was completed, highlighting what the thesis dealt with. Opting for modeling and simulation was based primarily on the fact that the candidate had a Bachelor's degree in automation and computers, having skills in this area. Later the departments of the Engineering Faculty of Hunedoara were reorganized again, and the candidate became a member of the Department of Electrical Engineering and Industrial Informatics and also head of the Department. In this period new programs of studies was authorized at the Engineering

Faculty of Hunedoara: Industrial Informatics (Bachelor's degree), Electrical Engineering and Computers (Bachelor's degree), and Informatics Techniques in Electrical Engineering (master degree). These new programs of studies allows to the candidate to do research in the field of computers applied in electrical engineering.

This very brief overview of the evolution of the candidate was presented in order to justify the research directions addressed by her. These are the followings:

- Modeling, simulation and identification systems applied in electrical engineering and in other fields as well;
- Artificial and computational intelligence applied in electrical engineering and in other fields;
- Contributions on developing of interactive educational software

These directions are not completely independent one from the other. Most of the candidate's research can fit into the first two directions. The candidate continued the research she had begun with her PhD thesis with the first two directions. She therefore attempted to improve the models of the electric arc studied in the thesis and also studied new models. The study of intelligent techniques such as neural networks or hybrid neuro-fuzzy systems for modeling the electric arc can also be considered a continuation of her doctoral research.

In this thesis, the published scientific results which are based on research conducted in the aforementioned research directions mentioned previously will be presented. The emphasis will be placed on the contribution of the candidate to the research, as a principal investigator, most of which was made in collaboration with research teams.

2.1. OVERVIEW OF ACTIVITY AND RESULTS, 2002 – 2015

During 2002 – 2015 the candidate published over 130 papers among which 41 (13 of which as first author) are indexed in the ISI Web of knowledge database (9 in journals and 32 in conference proceedings) and 73 in other international databases (Scopus, ACM, Inspec, IEEExplore, Engineering Village etc.).

In the aftermath of her PhD thesis defense, the candidate, on one side, has continued her research in the field of her PhD thesis and on the other side she has approached other interdisciplinary fields. Hence one of the fields the candidate pursued to study consists in modeling, simulation and system control, thus continuing her research regarding the modeling of the electric arc. The most important works from this period are as follows: [Pănoiu M 13a], [Pănoiu M 13b], [Pănoiu M 09a], [Ghiormez 13b], [Pănoiu M 08a, c, d, e, f, g, h, i], [Pănoiu C 08g], [Pănoiu M 07a]. Certain studies accomplished alongside other researchers can also be classified as developing to the field of modeling and simulation, studies testified in the following papers: [Rob 09b], [Osaci 09], [Abrudean 09a].

During the same period the candidate has developed research in applied artificial intelligence. Thus the candidate investigated the possibility of applying intelligent techniques in modeling the electric arc, but also of using them in fields as: applications of fuzzy logic systems ([Pănoiu M 14 a], [Pănoiu M 10b], [Pănoiu M 10e], [Pănoiu M 12a], [Rusu-Anghel 11]), applications of artificial neural networks ([Pănoiu M 13b], [Pănoiu M 13c], [Pănoiu M 13d], [Tirian 09]), the usage of heuristic algorithms in the game theory ([Pănoiu M 11b], [Pănoiu M 12b]). Also in the last period the candidate was study the possibility of transforming the written language into speech (Text – to speech) in the paper [Pănoiu M 14b], or video streaming technologies [Pănoiu M 14c]. Another subfield of artificial intelligence is multi-agent systems and distributed programming. The study of this field was undertaken by a research team, in which the candidate was member. The evidence of this striving can be found in the following papers: [Muscalagiu 13 a,b], [Muscalagiu 11], [Muscalagiu 10 a,b].

Another field approached in the candidate's PhD thesis is the quality of electric power, and electromagnetic pollution, a field in that the candidate continued studying after obtaining her PhD with the help of a research team. Some papers that belong to this category: [Pănoiu M 10c], [Pănoiu M 08b], [Pănoiu C 11a,b,c], [Rob 11a,b], [Pănoiu C 10b], [Rob 10 a,b,c], [Rob 09a].

In this field candidates participated in the competition for grants and projects financed by the Balkan Environmental Association (http://www.benaweb.gr/), grants that have focused on the topic of electromagnetic pollution problem. The first grant was developed in 2007 with the title: "*Study about harmonic pollution mitigation in the electric power supply network at ultra high power electric arc furnances",* partener S. C Mittal Steel. In 2008 the second grant entitled "*Measure of the electromagnetic polution level caused by mobiles and wireless electronic equipments",* partener S. C Comser SRL was developed. The investigations of these grants were resulting in a series of articles published in journals and conferences ISI / IDB. Some of the works mentioned above are the results of these research grants.

In the period 2000-2004 the candidate has been activated as a research team leader (for 2 phases) to a research grant RELANSIN entitled "*Improving energy quality indicators in electric steel plants and their implications on the technological process*".

The candidate was included in research teams for grants and international projects:

- "Complex relay for the protection of the contact line against abnormal operating modes". CNCSIS – GRANT A
- "Advanced technologies for the control of industrial processes of surface tempering inductively heated pieces", Program 4 "Partnerships in Priority Fields", 2007-2013
- "Fuzzy expert systems for LC protection and associated equipment from the electric railway transportation" SC Softronic SA Craiova
- "Study about harmonic pollution mitigation in the electric power supply network caused by electrical locomotive",

Between 2010 and 2012 the candidate was the project manager of a project financed through European funding, entitled: "Partnership for conducting practical training in the field of information technology and communications", POSDRU/22/2.1/G/40356"

Scientific activity carried out by the candidate had an international impact in the past and also in present. This can be proving by the following:

The candidate has reviewed for the following ISI and BDI foreign journals:

- Simulation Modeling Practice and Theory, ISI journal
- Computer application in engineering education, ISI journal
- Wiley International Transactions on Electrical Energy Systems, ISI journal,
- IET Generation Transmision and distribution ISI journal,
- Progress in Electromagnetics Research, BDI - Scopus

Also, the candidate was reviewer and International Program Committee member for several conferences, such:

- 2013 International Conference on Applied Sciences, Wuhan, China, ISI Proceedings
- The 17th IASTED International Conference on Applied Simulation and Modelling ~ASM 2008~,
- The 18th IASTED International Conference on Applied Simulation and Modelling ~ASM 2009 ~
- The 19th IASTED International Conference on Applied Simulation and Modelling ~ASM 2011~
- The 20th IASTED International Conference on Applied Simulation and Modelling ~ASM 2012~
- The 5th IASTED International Conference on Modelling, Simulation, and Identification ~MSI 2014~
- 6th WSEAS International Conference on Education and Educational Technology (EDU'07), 2007, ISI Proceedings
- 8th WSEAS International Conference on Applied Informatics and Communications, 2009, ISI Proceedings
- 9th WSEAS International Conference on Signal Processing, Computational Geometry and Artificial Vision (ISCGAV '09), 2009, ISI Proceedings
- 9th WSEAS International Conference on Applied Informatics And Communications, 2010
- 8th WSEAS International Conference on Systems Theory and Scientific Computation, 2008, ISI Proceedings
- 13th WSEAS International of Computers, 2009, ISI Proceedings

The candidate was invited and participated as plenary spekear at 3 international conferences (of which 1 is ISI and two IDB) and one national:

- *About the Possibility of Power Quality Improvement in Ultra-High Power EAF* , 13th WSEAS International Conference on Electric Power Systems, High Voltages, Electric Machines, 2013, BDI
- *Comparative Study and Simulations for Classic and Advanced Models of the Electric Arc*, 12th WSEAS International Conference on APPLIED INFORMATICS AND COMMUNICATIONS (AIC '12), 2012, BDI

- *Variable Step Adaptive Algorithms in Controlling Industrial Distorted Loads*, 13th WSEAS International Conference on Computers, 2009 ISI
- *Simularea unor procese pe baza modelării instalaţiei cuptorului trifazat cu arc electric,* Conferinţa Aniversară Hunedoara, 2001

The candidate has many citations in the literature:

- 28 citations in the database ISI Web of Knowledge index and h-index 3 .
- 77 citations in other international databases (Scopus, ACM, Google Scholar) and index h-index 3 in Scopus and h-index 8 in Google Scholar.

Besides these professional skills and scientific skills candidate has demonstrated in organizational and managerial way the followings:

- Competences and abilities in human, material and financial resources management;
- Competences in using information and communication technologies;
- Project management competences

Therefore:

- Since 1996 he did part of the Faculty Council of Engineering Hunedoara.
- In 2004 he was elected head of the Electrical Engineering Department
- In 2007 he was elected to the position of Director of Electrical Engineering and Industrial Informatics Department
- Between 2008 - 2012 he was the Director of Lifelong Learning Department, which is a self financing department
- Member of teams responsible for monitoring curricula por the following study programs: Industrial Informatics, Electromechanics, Informatics Techniques in Electrical Engineering
- In the current Council of the Faculty is Head of the Committee of Curricula and Syllabi's.
- Also from 2012 is part of the Council Department of Electrical Engineering and Industrial Informatics, and of the Bureau of the Department.
- In the Council Department is Head of the Didactical Commission and of the Commission's Human resources

2.2. CONTRIBUTION TO MODELING, SIMULATION AND CONTROL FIELD

This represents the main field of study researched by the candidate after obtaining her PhD degree in 2001. A part of research accomplish in this field is resulted from developing a Relansin program research grant in wich the candidate activated as a team leader în 2002 and 2004. As well a part of researches in this field is resulted from another research grant in 2007 where the candidate was project manager. Therefore, in the main area of research the candidate worked on the modeling and simulation of the electric arc furnace, thus continuing the work she had done for her PhD thesis. Furthermore, the candidate, alongside other researchers from the institute, has employed artificial intelligence techniques, especially artificial neural networks, for modeling and simulation of the processes that occur in the electrical network of the electric arc furnace. These will be presented in next chapter.

2.2.1. Electric arc modeling

Electric arc furnaces are among the most frequent and modern steelmaking systems. These have the advantage of high power, but also of high capacity, some of them reaching 120 tons. Yet these furnaces have certain disadvantages. The main one is caused by the nonlinearity of the electric arc. Any nonlinear element used in an electric circuit causes a series of issues within the electrical supply system, namely reactive power, harmonic currents, low power factor, the flicker effect and unbalanced loads (in the case of the three-phase AC furnaces this is due to the different lengths of the three electric arcs). All these problems have to be at least partially eliminated. The study of the behavior of the electric arc in different situations has therefore proven to be useful. An effective study can also be made using the electric arc models as the basis of the simulation of the entire electrical network of the furnace. As a result of this simulation, possible solutions for improving the quality of the electric energy, in the case of the electric arc furnace, can be identified. Such a study can be found in the candidate’s PhD thesis, a study regarding the performances of some of the electric arc models. The quality and performances of the models studied are evalued by comparing the simulation results based on these models with measurements obtained from the electric power network supply of a real three-phased electric arc furnace. The measurements were taken from the secondary winding of the transformer that supplies the electric arc furnace. The simulations in functioning of the furnace were made using the PSCAD EMTDC simulation environment, a programming environment especially made for simulating electric power systems.

During the time following her PhD thesis, the candidate continued to study electric arc models, research substantiated through papers published in journals and international conferences: [Pănoiu M 13a], [Pănoiu M 13b], [Pănoiu M 13d].

2.2.1.1. The electric arc supplied by AC voltage

The electric arc is a highly luminous electric discharge generated between 2 electrodes (anode and cathode) through which a high-intensity current flows. A side-effect of this discharge is the generation of a large quantity of thermal energy that is used to melt scrap metal inside the furnace.

The equivalent AC supply circuit for the electric arc is presented in figure 2.2.1. In this figure, R_a represents the equivalent (nonlinear) resistance of the electric arc, r and L are the resistance and the inductance of the supply source, V_s is the AC supply voltage and i_A the current flowing through the electric arc.

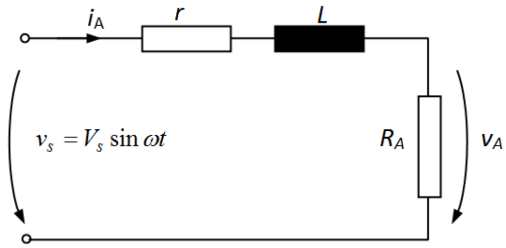


Fig. 2.2.1. The supply circuit of the electric arc

The rectifying effect of the AC electric arc

In the case of the AC electric arc, as shown in [Kimblin 74], the roles of the anode and the cathode reverse periodically according to the frequency of the supply voltage V_s, which has a sinusoidal variation, that can be seen in figure 2.2.2. If presumed that there is no phase shift between the voltage and the current, the flow of current through the arc can be indicated based on data represented in figure 2.2.2. Before igniting the electric arc the current is null ($i_s = 0$), since there is no current flowing through the arc. In this situation, the voltage between the electrodes connected to the source is equal to the supply voltage, v_s varying sinusoidal. If the ignition conditions are accomplished (local ionization, heating, etc.) the source voltage continues to have a sinusoidal variation on the 0 – 1 portion of the graph. In point 1 the source voltage reaches the ignition value V_{ig} which is high enough to accelerate the charge carriers which produce new ions through collisions. Through this, the space between the electrodes becomes electrically conductive and the difference of electrical potential between the two electrodes decreases to the V_{ex} (extinction voltage) value. Since the source is capable of producing a voltage $v_s > V_{ex}$, between points 1 and 2, the arc will burn steadily through this portion.

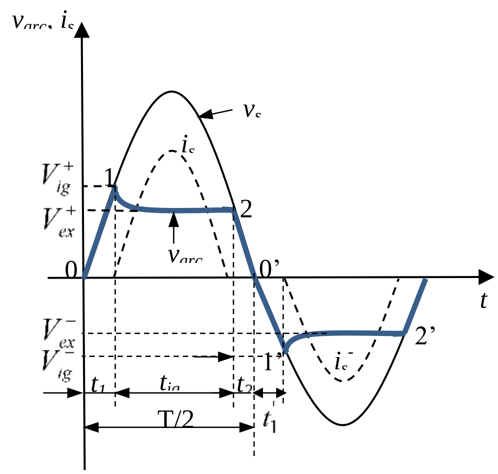


Fig. 2.2.2. The time variation of the arc voltage v_{arc}, the arc current i_s and the supply voltage v_s.

On the 2 – 0' portion, the source produces a voltage V_{ex} lower than the V_{ex} voltage necessary for the arc to burn, hence the arc interrupts. A similar phenomenon also takes place on the negative semi-period starting from 0'. The result is that the arc burns only between points 1 – 2 and 1' – 2', where the current varies according to i_s curve.

It can be observed that the arc burns intermittently and has burn breaks t_1+t_2, when $i_s \to 0$.

If the electrodes are producted by the same material as the scrap metal and their dimensions and cooling conditions are the same, the ignition voltage on the positive half cycle V_{ig}^{+} is equal to the the ignition voltage on the negative half cycle. The result is that the extinction voltages, V_{ex}^{+} , and V_{ex}^{-} are equal and positive and negative cycles of the current variation are symmetrical, hence:

$$-i_s(t) = i_s'\left(t + \frac{T}{2}\right) \tag{1}$$

In reality the electrodes are produced by different materials than the scrap metal, and their dimensions and cooling conditions are completely different. If taking into account the different cooling conditions of the electrodes, which are usually produced by graphite and the scrap metal, the result is that $V_{ex}^{+} \neq V_{ex}^{-}$ meaning that the arc voltage and current will be asymmetrical even if the arc has a sinusoidal (symmetrical) voltage source.

$$-i_s^{+} \neq i_s^{-}\left(t + \frac{T}{2}\right) \tag{2}$$

In this situation the electric arc is a better conductor in one direction than in the other one, so has a similar effect as a rectifier (figure 2.2.3). This effect has a negative influence on the stability of the arc. During the half cycle in which the current is low, the ionizations are more reduced and the tendency to quench increases.

Various methods have been presented in literatures in order to simulate this phenomenon [Alzate 11], [Gandhare 07].

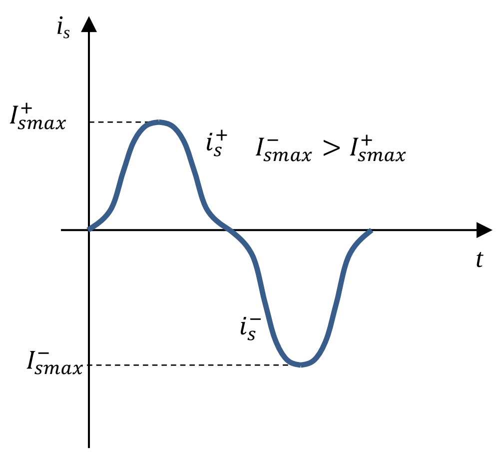


Fig. 2.2.3. The rectifying effect of the electric arc

The modeling of the electric arc used in electric arc furnaces is a problem that has been studied before in many bibliographic references. As can be observed in paragraph 2, the electric arc has certain specific characteristics that must be included in the implemented model. Modeling the electric arc represent a difficult task due to the nonlinear, rectifying, dynamic and, in some cases, random character of the electric arc. The task of modeling the arc is troublesome also due to the stochastic nature of the electric arc [Cano Plata 05], [Golkar 07], [Anuradha 08], etc.

The electric arc also depends on the stage of steelmaking the furnace is in. Other elements that influence the electric arc are the power transformer that supplies power to the furnace and the impedance of the flexible cables that supply power to the electrodes. The flexible cables are moving while the system is running and this movement modifies the length of the electric arc. Therefore, it is not easy to identify a static model for the electric arc because it depends in a large measure on the working conditions.

A list of a few categories of the electric arc models studied so far present in scientific literature consist in:

- Models based on empirical relationships between the diameter or the length of the arc, the voltage and the current flowing through the arc [Hooshmand 08a], [Hooshmand 08b], [Dehkodi 07], [Golkar 07], [Emanuel 00], [Chang 04] , [Sousa 99], [Montanari 94] , [Tang 97];
- Models that use the voltage - current characteristic of the electric arc [Islam 12] , [Gomez 10], [Sarem 10], [Golkar 07] , [Cano Plata 05], [Chang 04], [Zheng 00],[Varadan 96];
- Models that use nonlinear and time-varying resistors [Chang 04], [Petersen 95];
- Models based on voltage sources [Göl 10], [Hocine 09];
- Models that use stochastic processes [Esfahani 12] [O'Neill 01];
- Models that are based on intelligent techniques, such as neural networks [Sadeghian 00], [Sadeghian 99b], [Mazumdar 06],[O'Neill 01], [Wieczorek 08], [King 96], fuzzy logic [Sadeghian 99a] or hybrid neuro – fuzzy systems [Sadeghian 11], [Wieczorek 08], [Haruni 08], [Wang 05];

The candidate has also attempted modeling the electric arc in the aftermath of her PhD ([Pănoiu M 13a], [Pănoiu M 13b], [Pănoiu M 13d]) and has used the studied models in papers regarding the subject of the operating mode of the electric arc furnaces [Pănoiu M 09a], [Pănoiu M 08a], [Pănoiu M 08b], [Pănoiu M 08c], [Pănoiu M 08d], [Pănoiu M 08e], [Pănoiu M 08f], [Pănoiu M 08g], [Pănoiu M 08h], [Pănoiu M 08i], [Pănoiu M 08j], [Pănoiu M 07a], [Pănoiu M 07b], [Pănoiu M 07d], [Pănoiu M 07e].

In all of these models, which are classic models, a number of simplifying, limitations and approximations hypotheses have been made. A great disadvantage of these models is that, generally speaking, the process of estimating the parameters is not adaptive. At the same time an electric arc furnace is a complex nonlinear system with time-variable load in the melting process. Even certain process conditions can vary from one batch to another (such as the type of metal scrap that is used). Hence finding an adaptive model is important.

Intelligent techniques using fuzzy logic and artificial neural networks have also been suggested in order to model the nonlinearity of the electric arc and to eliminate the disadvantages of the classic models insufficiently thorough a mathematical standpoint.

In order to study the efficient control the EAF and improve the electric power quality, models of the electric arc that simulate the nonlinearity and random behavior of the electric arc were necessary to find.

The results of the simulation, namely the waveforms of the currents and voltages and the voltage – current characteristics, were compared to their measured values.

The simulations have been made using the PSCAD EMTDC program and Matlab with Simulink.

The single-phased diagram (EAF-single –line diagram) is presented in figure 2.2.4.

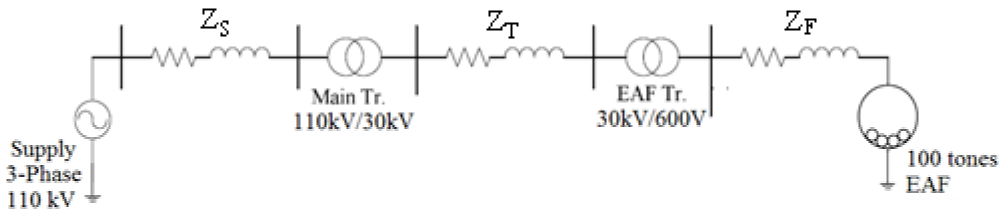


Fig. 2.2.4. The single – line diagram for the EAF

In figure 2.2.4. Z_S – is the impedance of high voltage power supply, Z_T – is the impedance of medium voltage power supply, and Z_F – is the impedance of low voltage power supply.

2.2.1.2. Models that use the voltage – current characteristic of the electric arc

A. Model based on linearization of the voltage – current characteristic

The model under analysis is described in [Pănoiu M 07c], [Golkar 07], [Islam 12] , [Gomez 10], [Sarem 10], [Golkar 07] , [Cano Plata 05], [Chang 04], [Zheng 00],[Varadan 96] is based on the linear approximation of the typical voltage-current characteristic of the electric arc. This model is given in relation (3).

$$u=\begin{cases} R_1\cdot i, & i\in[-i_1,i_1) \\ R_2\cdot i+V_{ig}\cdot(1-R_2/R_1), & i\in[i_1,i_2] \\ R_2\cdot i-V_{ig}\cdot(1-R_2/R_1), & i\in[-i_2,-i_1) \end{cases} \tag{3}$$

where,

$$i_1=V_{ig}/R_1 \tag{4}$$

$$i_2=V_{ex}/R_2-V_{ig}\cdot(1/R_2-1/R_1) \tag{5}$$

In relations (3), (4) and (5) the following parameters were used:

- R_1 – the line slope resulted when the voltage-current characteristic is approximated with a line ranging within $[-i_1,i_1)$;

- R_2 – the line slope resulted when the voltage-current characteristic is approximated with a line ranging within $[-i_2,-i_1)$ or $[i_1, i_2]$;
- i_1 – the value of the electric arc current reached at the ignition voltage of the electric arc (V_{ig});
- i_2 – the value of the electric arc current reached at the extinction voltage of the electric arc (V_{ex}).

This model is based on the real voltage current characteristics approximation. Another main feature of the modeling technique is that the model parameters depend on the power transmited to the load, thus the model parameters depend on the work condition. Because the model use the electric power consumed by the EAF, results that the model allows modifying the voltage – current characteristic in such a way to obtain a desired power in the load circuit.

The principle to obtain a desired active power is based on the fact that voltage – current characteristic area is equal with active power [Esfahani 13].

Starting from the model presented in relation (3) an improved model has been implemented, which extends the existing one, this being presented in relation (6). The proposed model approximates more accurately the typical voltage-current characteristic of an electric arc. When the electric arc voltage reaches the extinction voltage value, V_{ex}, arc voltage continues its variation for a moment of time and will not change it immediately. As compared to the model presented in [Golchar 07] and [Montanari 98], the following differences are:

- A different electric arc functioning zone is defined;
- In the case the value of the current is below $-i_2$ or above than i_2, one can notice that the voltage variation is constant, maintained at the extinction voltage value of the electric arc;
- The range in which the dynamic voltage-current characteristic can vary is larger than the one illustrated by the model presented in (3)

The improve model is also based on the fact that the area under the voltage – current characteristic is equal to the active power transmitted to the arc [Esfahani 12]. In figure 2.2.5. is shown the approximative variation for this model.

$$v = \begin{cases} R_1 \cdot i, & i \in [-i_1, i_1] \\ R_2 \cdot i + V_{ig} \cdot (1 - R_2 / R_1), & i \in (i_1, i_2] \\ R_2 \cdot i_2 + V_{ig} \cdot (1 - R_2 / R_1), & i > i_2 \\ R_2 \cdot i - V_{ig} \cdot (1 - R_2 / R_1), & i \in [-i_2, -i_1) \\ R_2 \cdot (-i_2) - V_{ig} \cdot (1 - R_2 / R_1), & i < -i_2 \end{cases} \tag{6}$$

Thus, the model parameters are:

$$i_1 = \frac{V_{ig}}{R_1} \tag{7}$$

$$i_2 = \frac{V_{ex}}{R_2} - V_{ex} \cdot \left(\frac{1}{R_2} - \frac{1}{R_1} \right) \tag{8}$$

$$i_m = k \cdot i_n \tag{9}$$

Parameters R_1, R_2 are the slopes for OA and AC segments. R_1 is depending on the electric arc power, *P*. Within this model, three functioning zones of the electric arc are distinguished, i.e. the two presented before, and the third zone is the one corresponding to the current values below i_2, respectively above $-i_2$. In this zone it can be noticed that the electric arc voltage is maintained constant at the value calculated with (10).

$$V = R_2 \cdot i_2 + V_{ig} \cdot (1 - R_2 / R_1) \tag{10}$$

When current of the arc falls below $-i_2$, the voltage is calculated with expression (11).

$$V = R_2 \cdot (-i_2) - V_{ig} \cdot (1 - R_2 / R_1) \tag{11}$$

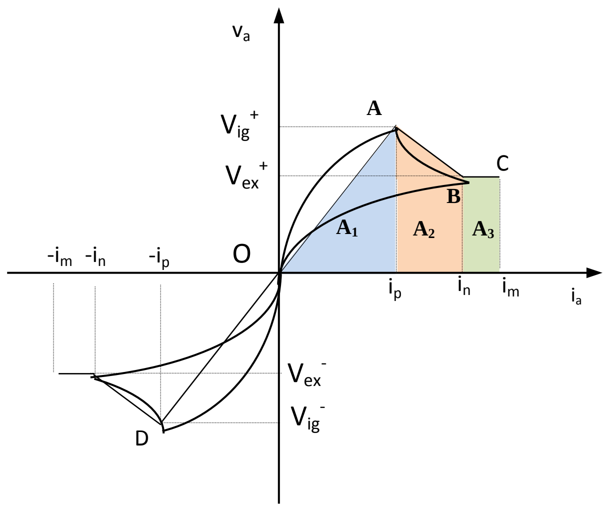


Fig. 2.2.5. The approximative voltage-current characteristic of the model.

Figure 2.2.6 shows a comparison between the two graphics, one being obtained with the existent model in the reference literature and the other with the first model proposed and illustrated in this paragraph. The both graphics are implemented in Matlab.

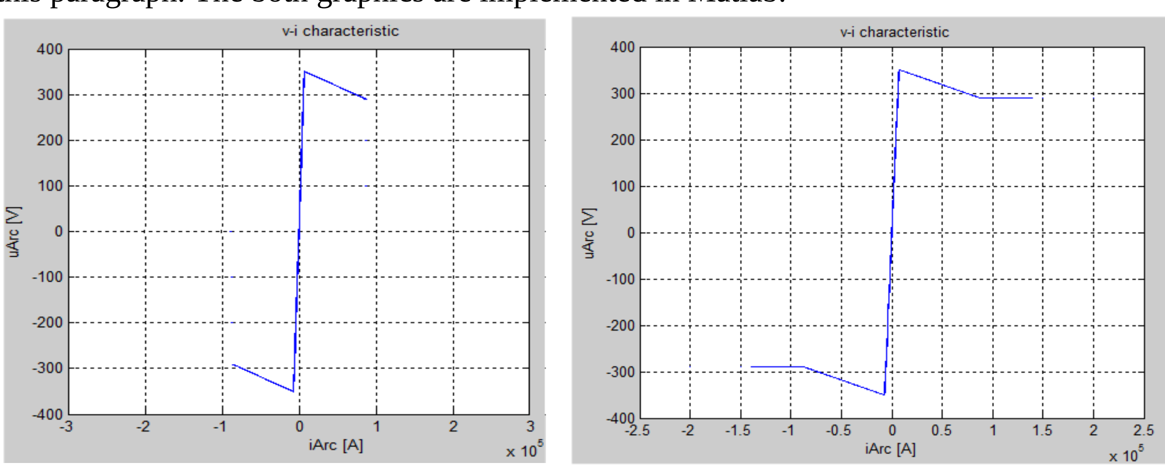


Fig. 2.2.6. The linear voltage-current characteristic obtained with the existent model and with the first proposed model.

An interface in the environment Matlab version 2012, which is presented in the followings, implemented to observe the influence of the model parameters over the voltage – current characteristic of the electric arc.

Figure 2.2.7 shows the interface implemented in Matlab used to simulate the electric arc behavior. The components given by this interface are used to modify the model parameters, i.e. R_1, R_2, V_{ig}, V_{ex}

A range of values for each parameter was selected, within these can vary. Also, the interface has four buttons, each one having a different function.

The *Load model* button has the role to open the proposed model implemented in Simulink (Matlab), and then the parameter values are transmitted from the interface to the Matlab function implemented in Simulink.

The *Simulation* button can be pressed after the *Load model* button was pressed. The simulation button will draw the dynamic voltage-current characteristic of an electric arc, as model parameters can be varied in real time to see their impact upon the electric arc.

The *Stop Simulation* button has the role to stop the simulation and this can be started only if the *Simulation* button is pressed.

The *Exit* button has the role to close the interface, when it is pressed.

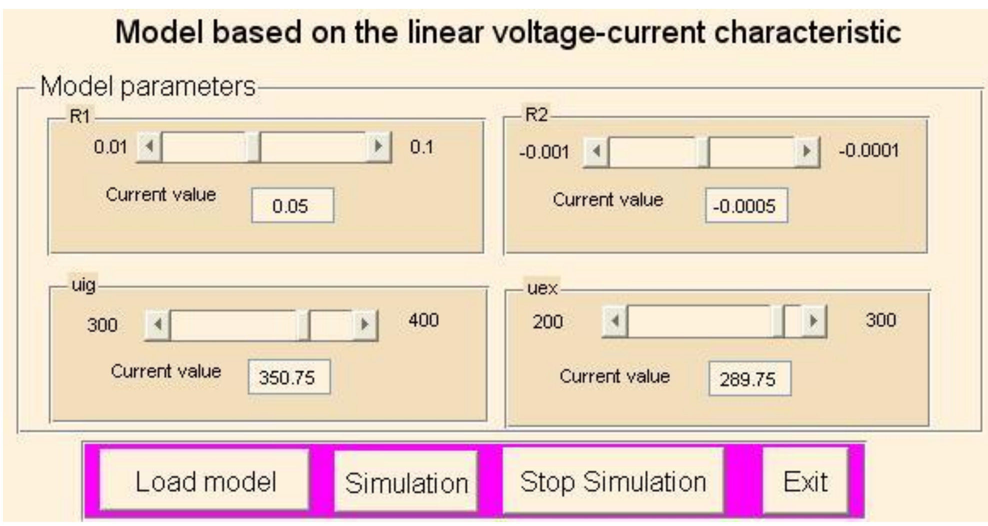


Fig. 2.2.7. The Matlab interface of the first proposed model.

Using this interface it can be obtained the dynamic voltage-current characteristic of the electric arc, which is presented in figure 2.2.8.

In the graph obtained from figure 2.2.8, it can be noticed that the interval in which the characteristic is defined is [$-2x10^5$, $2x10^5$] and the dynamic voltage-current characteristic is linear.

Comparing with the model presented in [Pănoiu M 07c], [Golkar 07], [Islam 12], [Gomez 10], [Sarem 10], [Golkar 07], the following differences are:

- A different functioning zone of the electric arc is defined;
- In the case the value of the current is below -i_2 or above than $i_{2,}$ it can be noticed that the voltage variation is constant, maintained at the extinction voltage value of the electric arc;
- The range within the dynamic voltage-current characteristic can vary is larger than the one illustrated by the model presented in previous references.

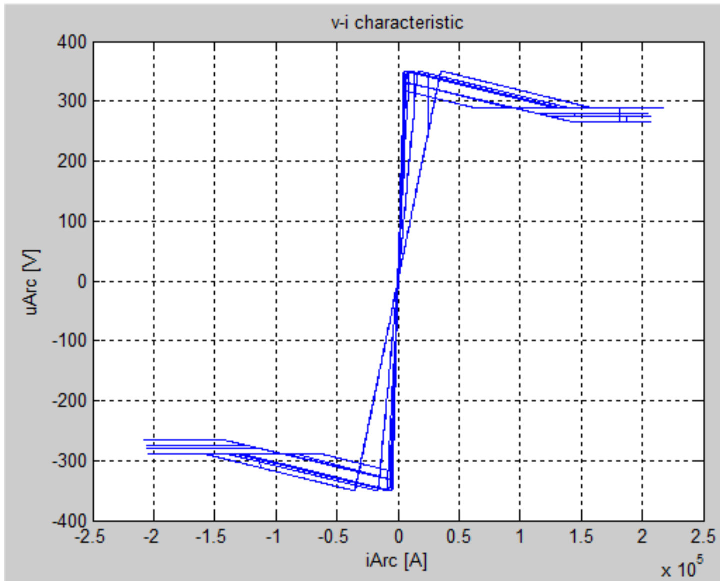


Fig. 2.2.8. The dynamic voltage-current characteristic obtained with the interface of the first proposed model

Figure 2.2.9 shows the current, respectively the voltage variations of the electric arc, obtained during the simultion of the electric arc behavior with previously proposed model.

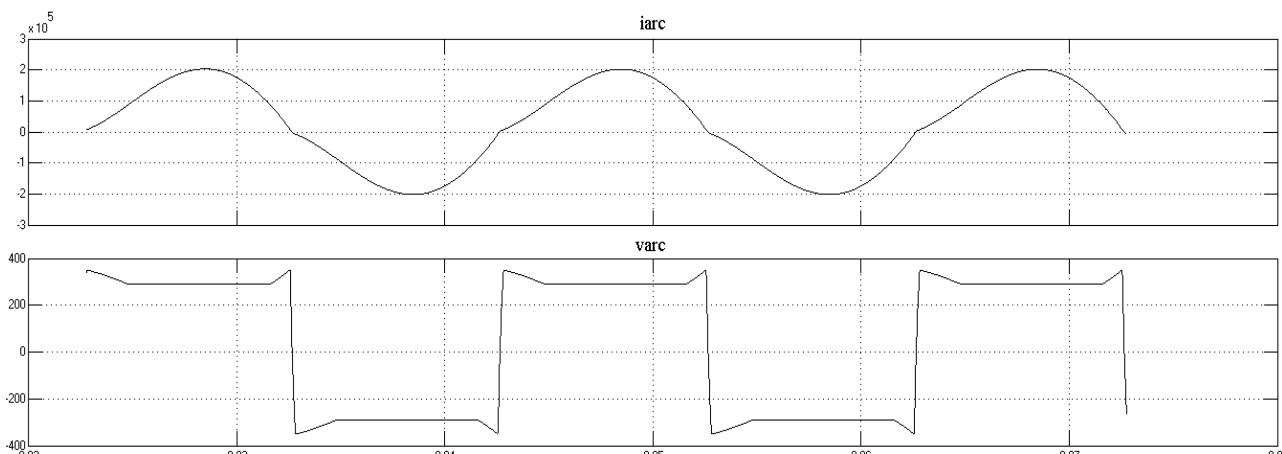


Fig. 2.2.9. The current and voltage waveforms of the electric arc

The model dependence of the desired power

One of the major requests that a model needs to fulfill is that it must allow modifying some parameters value that can be supervised in the real plant. Electric arc models are influenced by the voltage on the secondary side of the furnace transformer and also by the phase in which the technologic process is: meltdown or refining stages. Parameters that can be supervised and modified in the real plant are the distance between the graphite electrodes and the metallic bath and the tap of the furnace transformer. The distance between the electrodes and metallic bath can be modified in simulation by modifying the ignition and the extinction voltage of the electric arc. The tap of the transformer can be also modified in simulation by adjusting the voltage at the secondary side of the transformer that feeds the electric arc. In the real plant the charging material is loaded in the furnace tank and during melting process the tap of the transformer will be changed.

R_1 represents the slope of the linearization characteristic presented in figure 2.2.5. In order to impose a specified power to the electric arc, presented slope can be modified and so the voltage – current characteristic is also modified. R_1 parameter is given by the relation (4) and was determined by the following condition: the imposed power of the electric arc to be equal to area generated by the voltage – current characteristic. For the first quadrant this area is formed by areas A_1, A_2 and A_3. In function of the voltage from the secondary side of the power transformer, A_3 can be also nul.

$$R_1 = \frac{V_{ig} \cdot (2 \cdot V_{ex} - V_{ig})}{2 \cdot V_{ex} \cdot i_m - \frac{(V_{ig} - V_{ex})^2}{R_2} - P} \qquad (12)$$

The difference between V_{ig} and V_{ex} varies in 6 V ÷ 40 V domains and is different in the two cycles, [Esfahani 12], [Setayesh 13]. In this work it was used for V_{ex} the value 40 V.

One of the main problems which must be solved is the control of the active power. Because the active power depends on the area under voltage – current characteristic, the solution is to modify this area by modifying the V_{ex} (and also the V_{ig}). In this scope a LMS algorithm was used in order to modify V_{ex} as in relation (13):

$$V_{ex}(n) = V_{ex}(n-1) + \alpha \cdot (P - P_m) \qquad (13)$$

In relation (13) P_m is the measured power of the electric arc, *n* is current iteration, *n-1* is precedent iteration, α is the adapting factor.

Due to modifying of the length of the arc from the real process, V_{ex} also modifies his values. This model is implemented in PSCAD-EMTDC, the simulation scheme is presented in figure 2.2.10.

The EAF system is supplied from 110 kV high voltage power network through main power transformer T1, which is the supply transformer, HV/MV and steps down the voltage from 110 kV to 30 kV, and a 30 kV medium voltage switching station where the transformer T2, MV/LV is connected to the 30 kV and supply the EAF. The the parameters of the distribution supply system are the followings:

- Supply transformer T1: 100MVA, Y/Δ connection, 110kV/30kV,

- Furnace transformer T2: 73 MVA, Y/Δ connection, 30kV/0.56 ÷ 0.6 kV, depending on technological phase

PCC is the Point of Common Coupling, where another consumers can be connected as well. Z_s is the electric cable impedance, $Z_s = Rs + j\,2\pi f\,L_S$, where $Rs = 0.364\ m\Omega$ and $L_S = 0.09342\ mH$ if the system contains the symmetrical cable supplying, or can be different in function of configuration of cable that supplies the furnace electrodes.

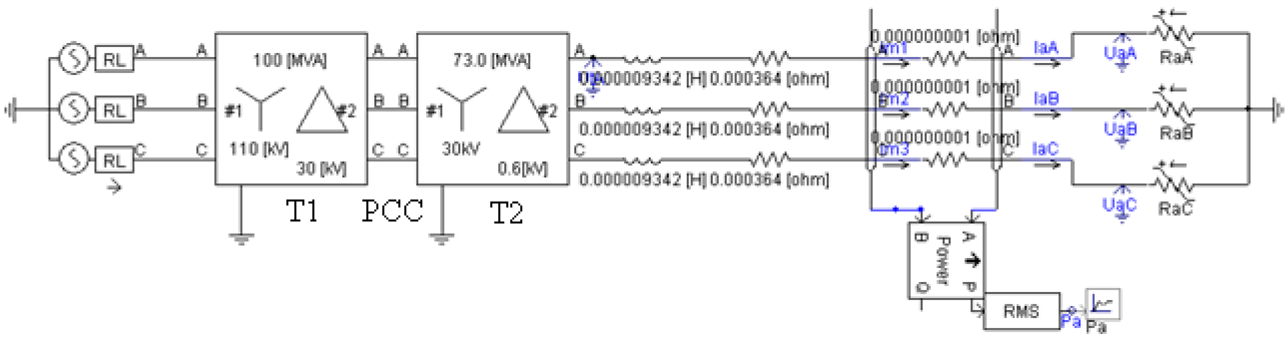


Fig. 2.2.10. The PSCAD – EMTDC simulation scheme

In order to define an embedded PSCAD custom component for model the electric arc, has used a feature of PSCAD – EMTDC program that allows the user to define their own component with parameters and for which it can be called FORTRAN subroutine (or C function or Matlab functions). In this case, a C function is called through a FORTRAN script. The model parameters can be chosen in such a way that the arc may be operated as interrupted arc or non-interrupted arc.

In order to facilitate the variation of the model parameters, a PSCAD-EMTDC simulation scheme for the electrical installation of an EAF was design, like the one from figure 2.2.10. The simulation scheme uses slider components that allow modifying the parameters during the simulations, as is shown in figure 2.2.11.

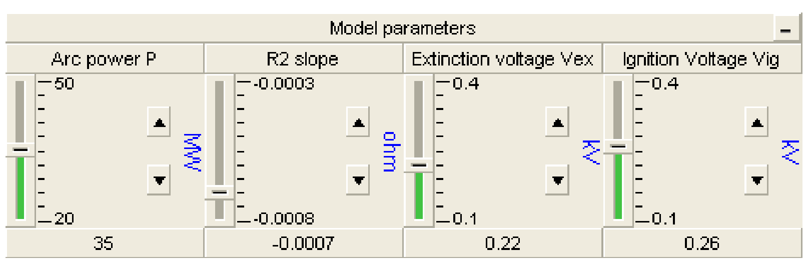
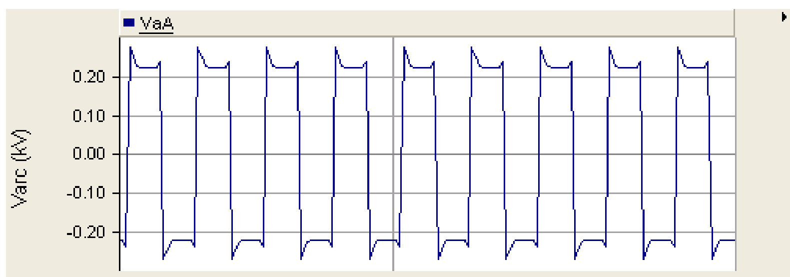


Fig. 2.2.11. Modifying the model parameters during simulation

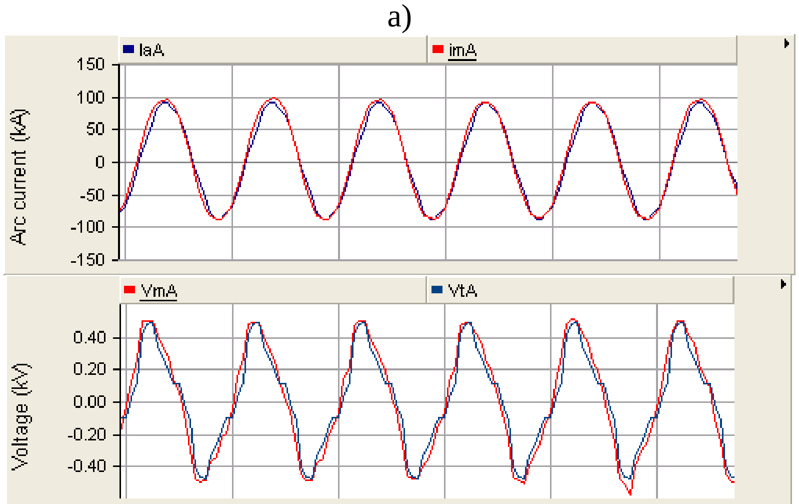
In order to validate the implemented model, comparisons between simulations and experimental results obtained in measurement in power plant of an 100 t EAF were made [Panoiu 09a]. A comparison result of simulations with experimental data was done both in terms of waveforms of currents and voltages, and in terms of voltage – current characteristic (actual and simulated). Figure 2.2.12 shows the PSCAD-EMTDC both the simulation and the measurements results. In this figure V_{aA} is the simulated arc voltage, I_{aA} is the simulated arc current, I_{mA} is the measured arc current, V_{tA} is the simulated voltage from the secondary side of the furnace transformer, and V_{mA} is the measured voltage also from the secondary side of the furnace transformer. Figure 2.2.12a shows the simulated arc voltage, figure 2.2.12b shows the arc voltage and current changes both in the measured and simulation results with the proposed model. According to figure 2.2.12b, it is observed that the simulation results both for voltage and for current are very close to the measured voltage and current.

Must be mentioned that is very difficult to measure the arc voltage, therefore the voltage - current characteristic from figure 2.2.13a has been obtained only from simulations. Figure 2.1.13b shows the voltage – current characteristic both for the measured and proposed model obtained in the secondary side of furnace transformer.

The originality and the main technical improvements proposed for this model consist in the fact that the model parameters depend on the area of the voltage current characteristic i.e. the arc power, and another novelty of the proposed model is the parameters asymmetry, that is the actual situation in case of EAF's. Another feature of the model is the possibility to prescribe an electric arc power thus making the *V-I* characteristic dependent on the operating condition.

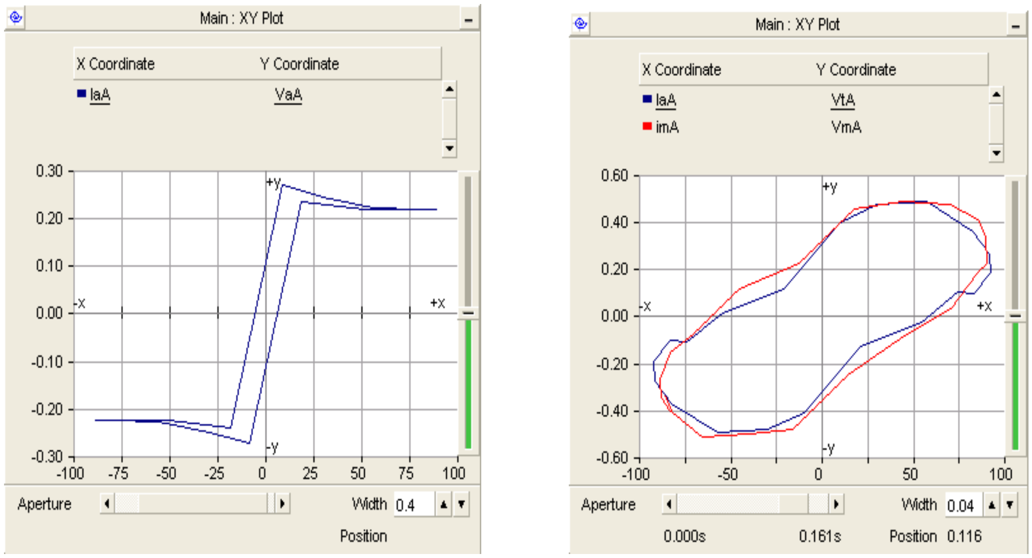


a)



b)

Fig. 2.2.12. a. Variation of the simulated arc voltage
b. Variation of the currents and voltages in the secondary side of furnace transformer (measured – red and simulated – blue).



a) b)

Fig. 2.2.13 a. Voltage - current characteristic of the electric arc.
b. Voltage - current characteristic of the electric arc measured in the secondary side of the power transformer (measured – red and simulated – blue).

This model can be used in power system studies with EAFs and investigated methods for power quality improvement in the point of common coupling. The simulation results and comparison with measured data described the advantages of the proposed method in modeling the EAF. The electric arc model implemented as an embedded PSCAD-EMTDC custom component is useful also to study the influence of all model parameters by using a proper graphical user interface.

B. The Model, based on the improved voltage-current characteristic of the electric arc

The model presented in this section and also in [Golkar 07], [Zheng 00] and studied by the candidate in [Panoiu M 13a] is described by relation (14). Comparative to the model presented in section A, this model considers that the voltage – current characteristic has a supplementary section which approximates more accurately the voltage-current characteristic of the electric arc.

First section, represented by *OA* segment from figure 2.2.14, corresponds to the re-ignition of the arc. During this time, the arc voltage has a proportional variation irrespective to the arc current and corresponds to the increasing of the arc voltage to the ignition voltage of the electric arc.

The second section, represented by *AB* curve in figure 2.2.14, corresponds to the melting process in which the arc voltage has an exponential decrease from V_{ig} to V_m (this is the average of the V_{ig} and V_{ex}) and the arc current increases from i_1 to i_2.

In the third section represented by *BC* segment the arc voltage drops slowly from V_m to V_{ex} and the arc current continues to increase to i_{max}. The slope of this segnment is R_2. After the current increases to the maximum value i_{max}, then it starts to decrease to the value i_3 with the slope R_3 of the segment CD. Obviously this phenomenon is the same on the negative half cycle.

As a remark, can be observed that R_1 slope is positive and R_2 and R_3 slopes are negative.

$$v = \begin{cases} i \cdot R_1, & if\ \ i \in (-i_3, i_1]\ and\ \ di/dt > 0 \quad (D'A) \\ V_{ex} + \left(V_{ig} - V_{ex}\right) \cdot e^{\frac{i_1 - i}{i_4}}, & if\ \ i \in (i_1, i_2]\ \ and\ \ di/dt > 0 \quad (AB) \\ V_m + (i - i_2) \cdot R_2, & if\ i \in (i_2, i_{max}]\ \ and\ \ di/dt > 0 \quad (BC) \\ V_{ex} + (i - i_3) \cdot R_3, & if\ i \in (i_3, i_{max}]\ \ and\ \ di/dt \le 0 \quad (CD) \\ i \cdot R_1, & if\ \ \ i \in (-i_1, i_3]\ \ and\ \ di/dt \le 0 \quad (DA') \\ -V_{ex} + \left(V_{ex} - V_{ig}\right) \cdot e^{\frac{i_1 + i}{i_4}}, & if\ \ \ i \in (-i_2, -i_1]\ \ and\ \ di/dt \le 0 \quad (A'B') \\ -V_m + (i + i_2) \cdot R_2, & if\ i \in (-i_{max}, -i_2]\ \ and\ \ di/dt \le 0\ (B'C') \\ -V_{ex} + (i + i_3) \cdot R_3, & if\ i \in (-i_2, -i_3]\ \ and\ \ di/dt \le 0 \quad (B'C') \end{cases} \quad (14)$$

In this model the values of the current were calculated with relations:

$$i_1 = v_{ig} / R_1, \quad i_2 = 3 \cdot i_1, \quad i_3 = v_{ex} / R_1,\ i_4 = 1.5 \cdot i_1$$

In order to improve the previous model, the behavior of the obtained active power irrespective to the i_{max} was studied. The simulations prove that the value of i_{max} leads to a limitation of active power which can be obtained, because as is well known the active power depends on the area under voltage – current characteristic. This allows obtaining an improved model which is presented in the following. This model has a supplementary segment CE, with zero slope in which current increases from i_{max} to an i_{max}'. The model is described by the relation (15).

$$v = \begin{cases} i \cdot R_1, & if\ \ i \in (-i_3, i_1]\ and\ \ di/dt > 0 \quad (D'A) \\ V_{ex} + \left(V_{ig} - V_{ex}\right) \cdot e^{\frac{i_1 - i}{i_4}}, & if\ \ i \in (i_1, i_2]\ \ and\ \ di/dt > 0 \quad (AB) \\ V_m + (i - i_2) \cdot R_2, & if\ i \in (i_2, i_{max}]\ \ and\ \ di/dt > 0 \quad (BC) \\ \boldsymbol{V_{ex} + (i_{max} - i_2) \cdot R_2}, & \boldsymbol{if\ i \in (i_{max}, i'_{max}]} \quad \boldsymbol{(CE)} \\ V_{ex} + (i - i_3) \cdot R_3, & if\ i \in (i_3, i_{max}]\ \ and\ \ di/dt \le 0 \quad (CD) \\ i \cdot R_1, & if\ \ \ i \in (-i_1, i_3]\ \ and\ \ di/dt \le 0 \quad (DA') \\ -V_{ex} + \left(V_{ex} - V_{ig}\right) \cdot e^{\frac{i_1 + i}{i_4}}, & if\ \ \ i \in (-i_2, -i_1]\ \ and\ \ di/dt \le 0 \quad (A'B') \\ -V_m + (i + i_2) \cdot R_2, & if\ i \in (-i_{max}, -i_2]\ \ and\ \ di/dt \le 0\ (B'C') \\ \boldsymbol{-V_{ex} + (-i_{max} - i_2) \cdot R_2}, & \boldsymbol{if\ i \in (-i'_{max}, -i_{max}]} \quad \boldsymbol{(C'E')} \\ -V_{ex} + (i + i_3) \cdot R_3, & if\ i \in (-i_2, -i_3]\ \ and\ \ di/dt \le 0 \quad (C'D') \end{cases} \quad (15)$$

The values of i_1, i_2, i_3 and i_{max} are the same. This fact leads to increase the area under the voltage – current characteristic, i.e. of the active power generated by electric arc. These researches were presented also in [Panoiu M 13a]. Figure 2.2.14 shows the approximative characteristics for this model. The improved models presented in section A and B help to obtain a voltage-current characteristic of the electric arc more close to the actual voltage – current characteristic. It can be noticed that these characteristics obtained with the proposed models represent more accurately the real characteristic of the electric arc, as compared to the model presented in [Golkar 07], because in reality, when the voltage of the arc reaches the extinction voltage value V_{ex}, the arc voltage continues its variation for a moment of time, and will not change it immediately. How long continues its variation, depend on the electric arc power.

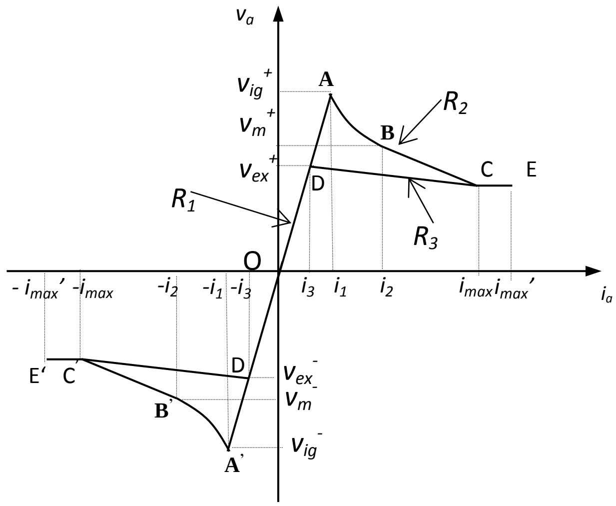


Fig. 2.2.14. The approximative characteristic for model from section B

This model was implemented both in Matlab and PSCAD-EMTDC and similar results were obtained. In [Pănoiu M 13a] Matlab results using this model was presented.

Figure 2.2.15 shows the voltage-current characteristic of the electric arc obtained with the model presented before. It can be noticed that this characteristic approximates more accurately the typical voltage-current characteristic of the electric arc. In order to obtain the dynamic voltage-current characteristic of the electric arc with this model, a graphical user interface was implemented, similar to the first proposed model, figure 2.2.16 showing this dynamic characteristic.

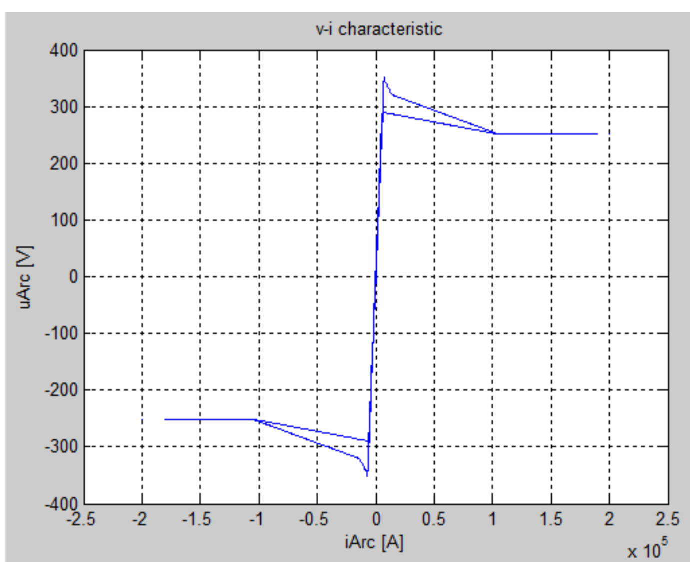


Fig. 2.2.15. The static voltage-current characteristic of the electric arc obtained with the proposed model, relation (16)

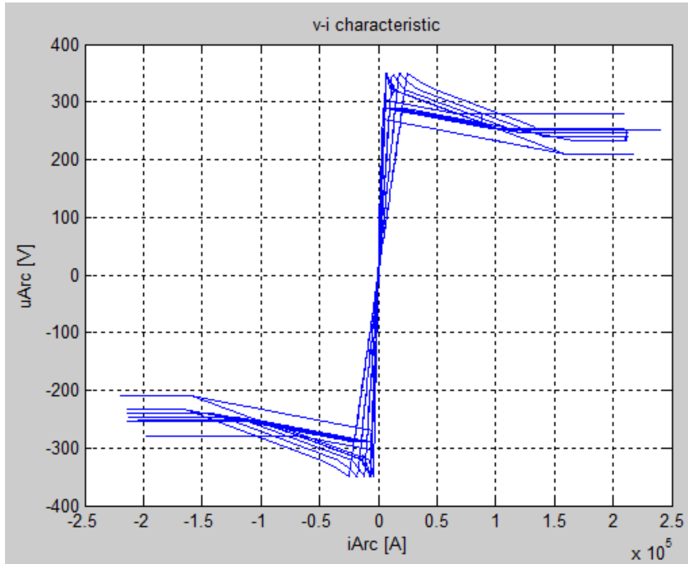


Fig. 2.2.16. The dynamic voltage-current characteristic obtained with the second proposed model, from relation (16).

The two improved models presented here help to obtain the dynamic or static voltage-current characteristics of the electric arc. It can be noticed that these characteristics obtained with the proposed models represent more accurately the real characteristic of the electric arc, as compared to the model presented in [Pănoiu M 07c], [Golkar 07], [Islam 12] , [Gomez 10], [Sarem 10], [Golkar 07], because in reality, when the voltage of the arc reaches the extinction voltage value, V_{ex}, the arc voltage continues its variation for a moment of time, and will not change it immediately. Based on these models, other models that accurately approximate this characteristic can be obtained.

Figure 2.2.17 illustrates the current, respectively the voltage variations of the electric arc obtained during the simulation of the electric arc behavior with the second model proposed before.

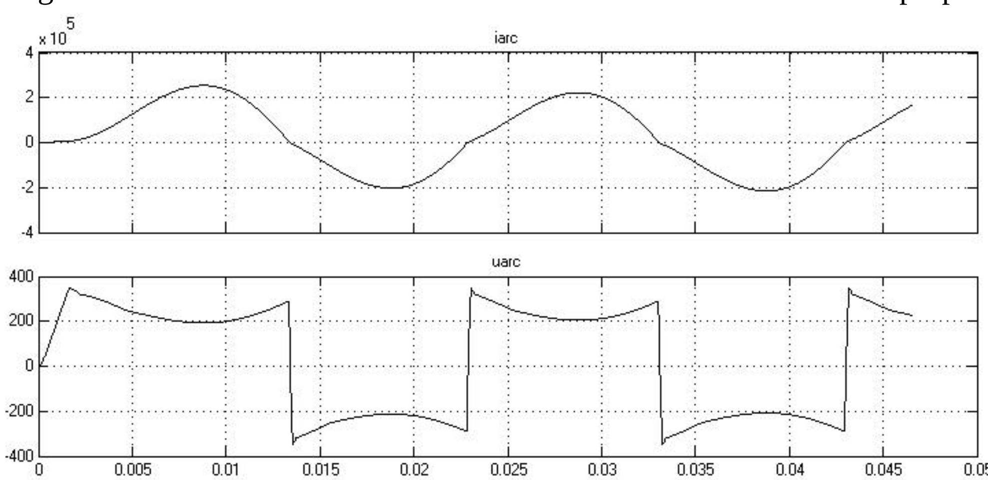


Fig. 2.2.17. The current and voltage waveforms of the electric arc for the second proposed model

Also, in figure 2.2.18 and 2.2.19 comparisons with measured values of voltages and currents are also shown. In these figures, with red line was represented the measured values and with blue lines was represented the simulated values.

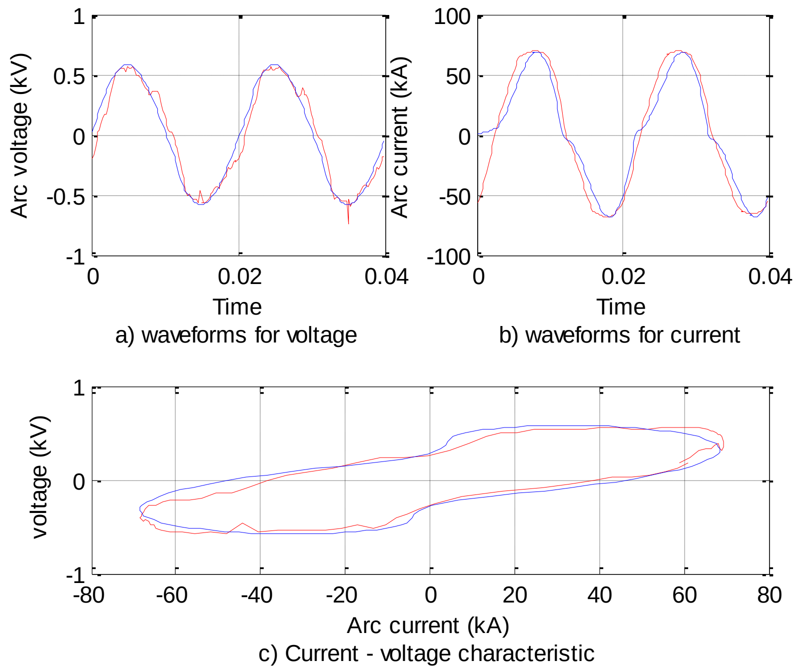


Fig. 2.2.18. Measured and simulated results for the melting stage

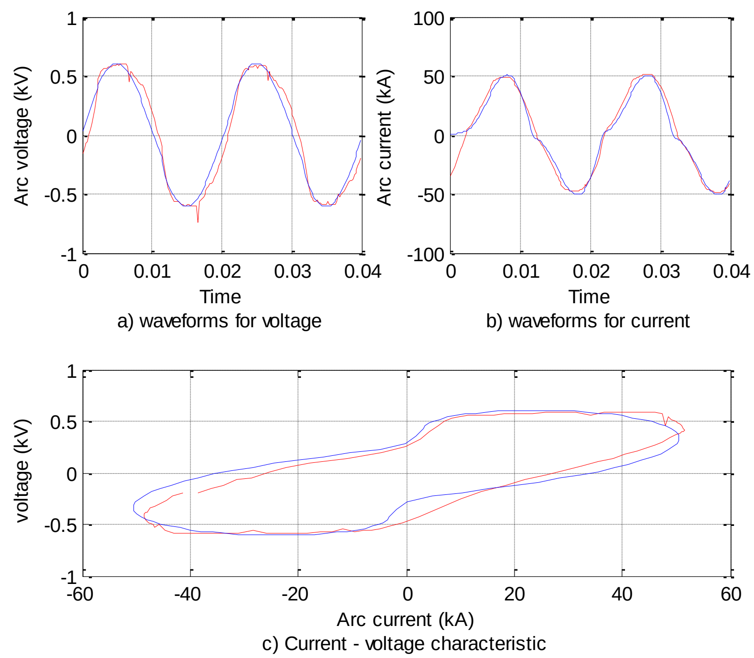


Fig. 2.2.19. Measured and simulated results for the refining stage

C. Model 3 based on the voltage – current characteristic of the electric arc

Another model, also based on voltage – current characteristics of the electric arc was studied and presented in [Ghiormez 13] and [Golkar 07].

As it was presented for the other models, there are three working phases of the electric arc. In the first one, the electric arc voltage increases to the ignition voltage of the electric arc, so the electric arc reignites. Hereby, the other phase can take place.

In the second phase, the electric arc voltage has an exponentially drop from the ignition voltage of the electric arc to the V_{ex} voltage. In this phase take place the melting process of the metals, electric arc voltage being stable. This segment is approximated with an exponential function with a time constant τ_1.

In the third phase of the electric arc working zone, the arc begins to be extincted, its voltage keeps dropping, process which can also be assumed to be represented by an exponential function with the time constant τ_2.

The equations of the model

$$R_a = \begin{cases} R_1 & I \in [0, i_{ig}] \ \ and \ \ \dfrac{dI}{dt} > 0 \\ \dfrac{[V_{ex} + (V_{ig} - V_{ex}) \cdot e^{-\frac{I - i_{am}}{\tau_1}}]}{I} & I \geq i_{ig} \ \ and \ \ \dfrac{dI}{dt} > 0 \\ \dfrac{[V_t + (V_{ig} - V_t) \cdot e^{\frac{-I}{\tau_2}}}{I + i_{ig}} & \dfrac{dI}{dt} < 0 \end{cases} \tag{16}$$

Where:

$$I = |i(t)| \tag{17}$$

$$i_{ig} = \frac{V_{ig}}{R_1}, V_{ig} = (1.15 \cdots 1.5) V_{ex} \tag{18}$$

$$V_t = \left[\frac{I_{\max} + i_{ig}}{I_{\max}} \right] \cdot V_{ex} \tag{19}$$

With this model implemented in Matlab, the variation from figure 2.2.20 – 2.1.23 was obtained. So, in figure 2.2.20 the voltages and currents variation from the secondary winding of furnace transformer are shown. In figure 2.2.21 the voltage – current characteristic of the electric arc is shown, and in figure 2.2.22 and 2.1.23 measured (red) and simulated (blue) results for the melting stage respectively for the refining stage are also shown.

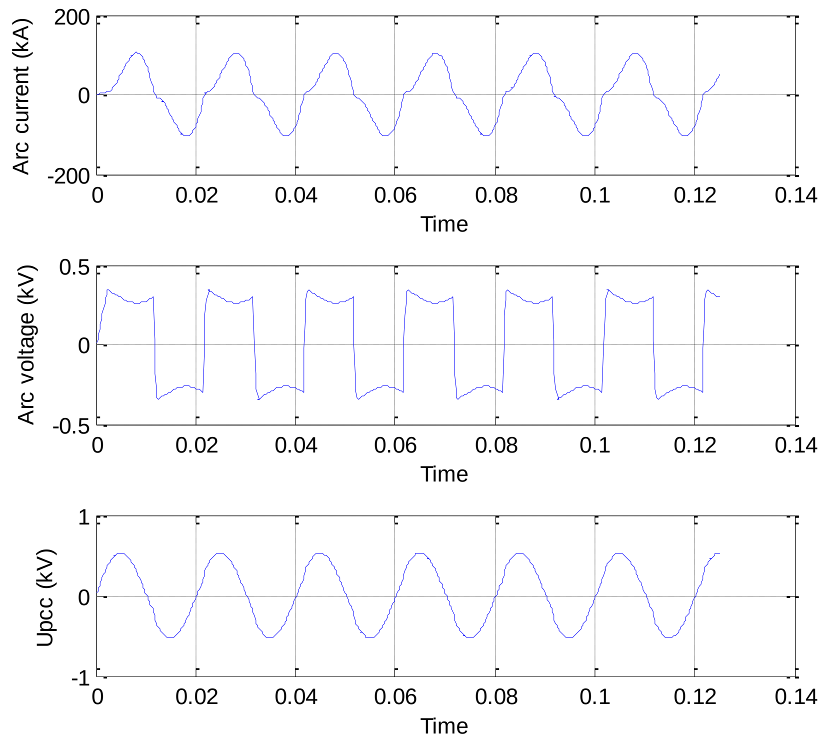


Fig. 2.2.20. The waveforms for i_{arc}, u_{arc} and voltage in secondary side of furnace transformer

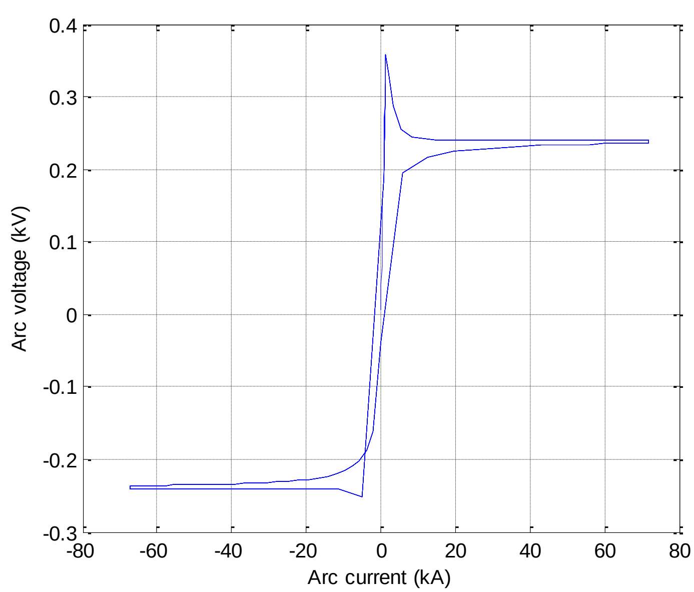


Fig. 2.2.21 The voltage – current characteristic of the electric arc

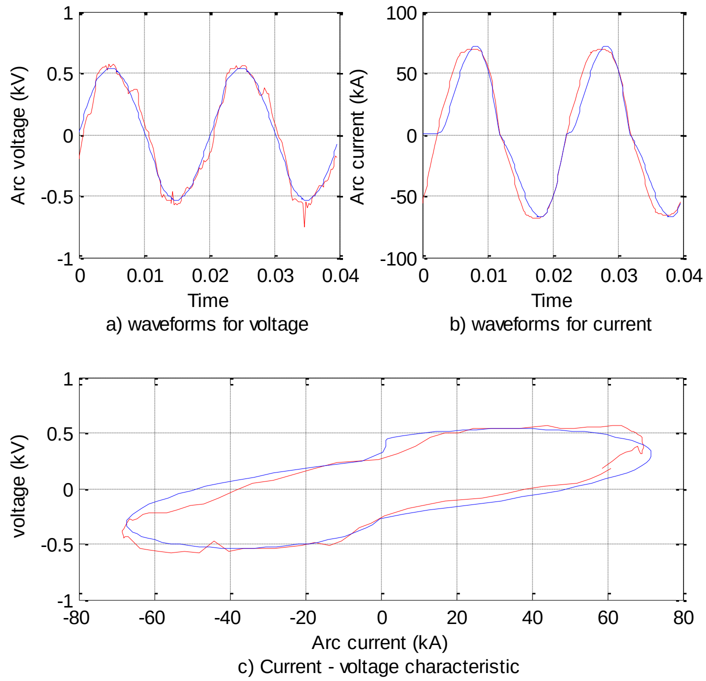


Fig. 2.2.22. Measured and simulated results for the melting stage

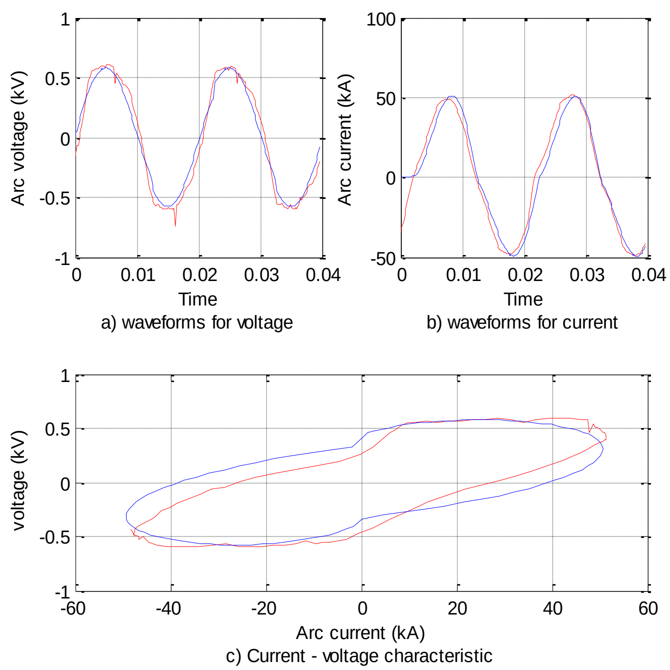


Fig. 2.2.23. Measured and simulated results for the melting stage

2.2.2. Using modeling to study the functioning of the electric arc furnaces

This paragraph provides a series of research made by the candidate in order to study the functioning of the electrical installation of the electric arc furnace and problems which can appear in its operation.

Due to the dynamic behavior of the electric arc, the EAF is an important source of disturbances: current harmonics, reactive power, flicker, voltage gaps [Sarem 10], [Gomez 10], [Hocine 09], [Xu 06], [Chitchian 03]. These disturbances are more important in case of Ultra High Power EAF (UHP-EAF). Because of these, solutions must be identified through which these disturbances should not be injected in the power supply network. First they have to identify an electric arc model. It is also useful to predict future values of arc current and voltage. Based on these values can take action to mitigate the disturbances.

One of the first research direction accomplished by the candidate refers to the study of the influence of the arc characteristics on active power, reactive power and distorted power.

Therefore, [Pănoiu M 07a] represents a performing study of the possibilities of controlling the electric arc power, in order to obtain maximum of the active power and reducing the reactive and distorted power. This study is based on the modeling the electric arc.

This model, given in [Hooshmand 08a], [Hooshmand 08b], [Dehkodi 07], [Golkar 07], [Emanuel 00], [Chang 04], considers the characteristic voltage - current described by a hyperbolic function:

$$V_A = V_A(I_A) \tag{20}$$

$$V_A = \left(V_d + \frac{C}{D + |I_A|}\right) \cdot signum(I_A), \tag{21}$$

where V_d, depending on the arc length, is the magnitude of the threshold voltage to which the voltage approaches as the current increases. In [Panoiu M 07g] this model has been experimentally validated using a set of measurements carried out in an electric arc furnace system. Measurements realised were presented in detail in the works [Pănoiu M 07d], [Pănoiu M 07e], [Pănoiu M 08f]. In the aforementioned works a serie of details on the design of filtering harmonic currents, reactive power compensation and balance the load of electric arc furnace were shown.

The C and D constants determine the difference between the current increasing part and current decreasing part of the current–voltage characteristic (C_a, D_a irrespective C_b, D_b).

The typical values are: V_d = 200 V, C_a = 190000 W, C_b = 39000 W, $D_a = D_b$ = 5000 A.

Ignition voltage value is obtained for I_A=0, $V_{ig} = V_d + \frac{C}{D}$

As the equivalent impedance of the short network is constant, it is obvious that if we use during simulations a fix value of the drop voltage, V_d, for a certain value of the voltage in the secondary of the furnace transformer, the active power dissipated in the electric arc will be constant, its value depending on the constants *C* and *D* from the relation (21). According to the above, the use of this model does not allow the correction of the active power of the electric arc, but the author demonstrated that the correction of the electric arc power can be done within loose limits using this model by modifying the drop voltage, which corresponds in practice to the modification of the distance between the electrodes and the metal bath [Pănoiu M 07a], [Pănoiu M 07b].

More details about the dependence of the waveform of the current through the arc and the secondary voltage of the transformer can be found in [Pănoiu M 06b], [Pănoiu M 07a], [Pănoiu M 07f].

Based on the previous model, the candidate studied by simulation how the designed filtering - compensation - balancing system acts. Thus, in [Pănoiu M 08b] a detailed study was conducted on how the current harmonic filters, the reactive power compensation and the load balancing system can influence each other and the results obtained for a number of such situations were depicted. The study was done starting from the proposed compensation system, load balancing installation and harmonics filter designed and presented in the papers [Pănoiu M 07d], [Pănoiu M 07e], [Pănoiu M 08f].

In order to obtain conclusions about the effects of reactive power compensation, load balancing and harmonics filters, simulations were made in five different cases:

- Without harmonics filters , power compensation and load balancing;
- Using only the system for reactive power compensation;
- Using only filters for harmonic currents;
- Using only the system for load balancing;
- Using power compensation, load balancing and harmonics filters.

Analyzing these results we found that:

- Using only the system for reactive power compensation, the power factor is close to 1, but the load remains unbalanced (the asymmetry coefficient for current, k_{ni} is increased). The current distortion is also accentuated (resulting due to the increasing value of total harmonic distortion of currents, Thd_i);
- Using only the system for load balancing, the asymmetry coefficient for current, $k_{ni\ is}$ more reduced, but Thd_i and k_p (power factor) have the same values.
- Using only the filters for current harmonics Thd_i is reduced but power factor is not improved and the asymmetry coefficient for current has even higher value.
- In generally the power quality in point of common coupling is much improved only in case of using all the elements (reactive power compensation, load balancing and harmonics filtering).

EAF operation on the electrodes position adjustment

The electrical items variation in different functioning regimes can be done only if we consider an arc length variation between 0, corresponding to the short-circuit regime, and a maximum value. The maximum value is determined in such a way that the electric arc is burning. For observing the variation area of the powers on the supplying line, the active power meters and reactive power meters was connected like in figure 2.2.24. The outputs of these meters permit to obtain the rms values.

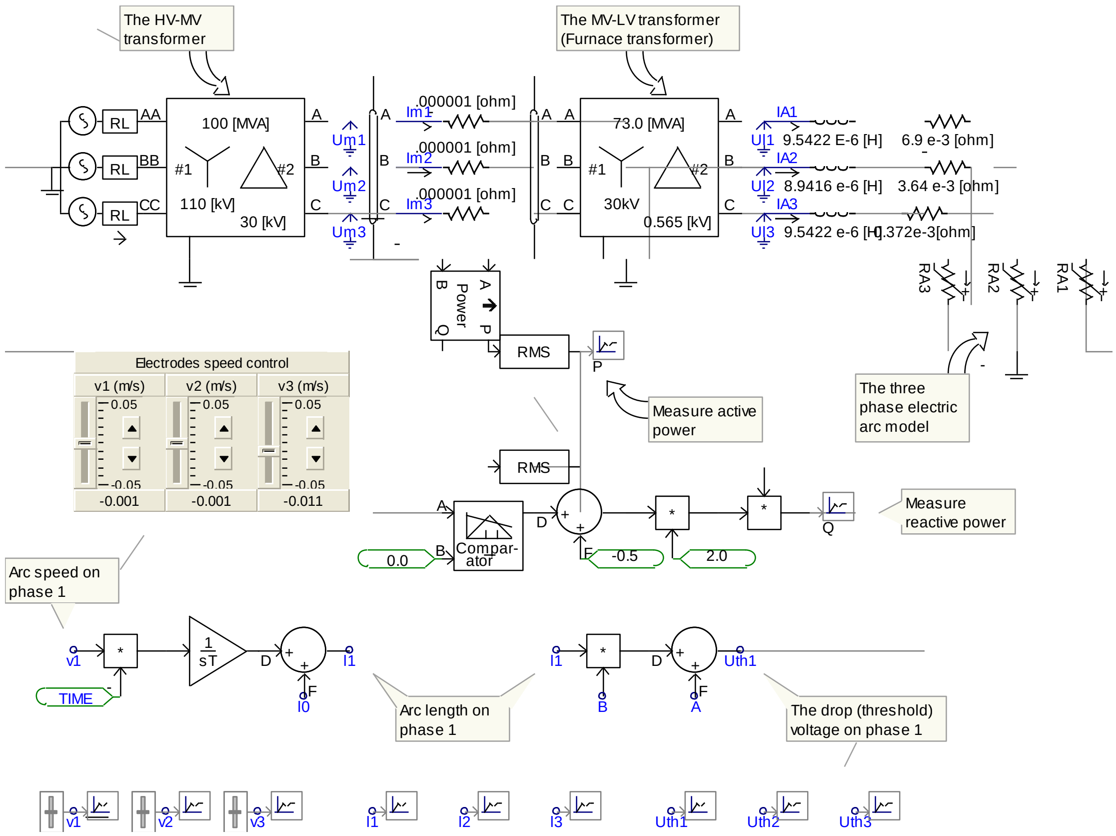


Fig. 2.2.24. Measured and simulated results for the melting stage

The model described by relations (20) and (21) assumes that the dynamic arc voltage–current characteristic must be an arc length function:

$$V_A = k \cdot V_{A0}(I_A) \tag{22}$$

where V_{A0} is the value of the arc voltage for a reference arc length l_0 and k is the ratio between the threshold voltage value for arc length l, $V_d(l)$ and the drop voltage value for arc length l_0, $Vd(l_0)$.

The dynamic model for electric arc is according to the relation:

$$V_d = A + B \cdot l \tag{23}$$

This study was made by using the model presented in relations (20) and (21) where the variation of the electric arc length was made using a variable coefficient k:

$$k(l)=\frac{A+B\cdot l}{A+B\cdot l_0} \qquad (24)$$

The electrodes position controlling is performed taking into account the real condition existing on the considered industrial plant. The maximum motion speed of the electrodes is *3 m/min (0.05 m/s)* and is reached in emergency regime, [Pănoiu M 07b]**.** Adjustment of the electrodes position is made on each phase independently.

The electrical items variation in different functioning regimes can be done only if we consider an arc length variation between 0, corresponding to the short-circuit regime, and a maximum value. For observing the variation area of the powers on the supplying line, the active power meters and reactive power meters were connected like in figure 2.2.24. The outputs of these meters permit to obtain the rms values.

The calculus of the drop voltage is made based on the relation (23), ([Pănoiu M 08i]) the implementation diagram being also in figure 2.2.24. The length of electric arc can be modified from zero to a maximum value, value determined by limiting the output values of the integrator, from figure 2.2.24. Simulation the functioning of the electric installation by modifying the length of the electric arc was made initially without harmonics filters, power compensation or load balancing. It was considering that the initial value of the electric arc was $l_0 = 16\,\text{cm},$ as well as the initial speed of the electrodes which was $v_1 = v_2 = v_3 = 0$ m/min. Then, the lowering of the electrodes up to the fulfillment of the short-circuit condition was commanded. After approximate 8 seconds, independently on each phase, the lifting of the electrodes with different speeds was commanded, up to the considered maximum length of the electric arc $l_{\max} = 26\,\text{cm},$ [Pănoiu M 07b]. In this way it practically the entire operation domain was covered, from the short-circuit regime up to the fulfillment of the conditions in which the electric arc does not ignite anymore. The simulation results are presented in figures 2.2.25 and 2.2.26. It can be observed that the highest value of the active power is obtained when the value of the arc length is aproximative 16 cm.

The reactive power is positive regardless the working regime, having values between *15-100 MVAR*, being therefore necessary the utilization of the installation for reactive power compensation. It can be observed that the domain in which the reactive power should be compensated is higher than the one chosen in case of designing the installation of the reactive power compensation, [Pănoiu M 08f].

This is due to the fact that the simulation included also the short-circuit regime where the reactive power has the value given by relation (25), considering the symmetrical short network and according to the diagram of circle of electric powers,

$$Q_{sc} = \sqrt{2}\cdot S_{cn} = 103{,}23 MVAR \qquad (25)$$

In the short-circuit regime of electrodes maximum values of the currents on the three phases are obtained, on the both supply lines and also minimum values of the voltages, fact due to the high loading of the 3-phase transformers. The rms values of the currents and voltages, presented in figure

2.2.25 are different on each phase, due to the different values of the load impedance and also due to different values on each arc lengths phase.

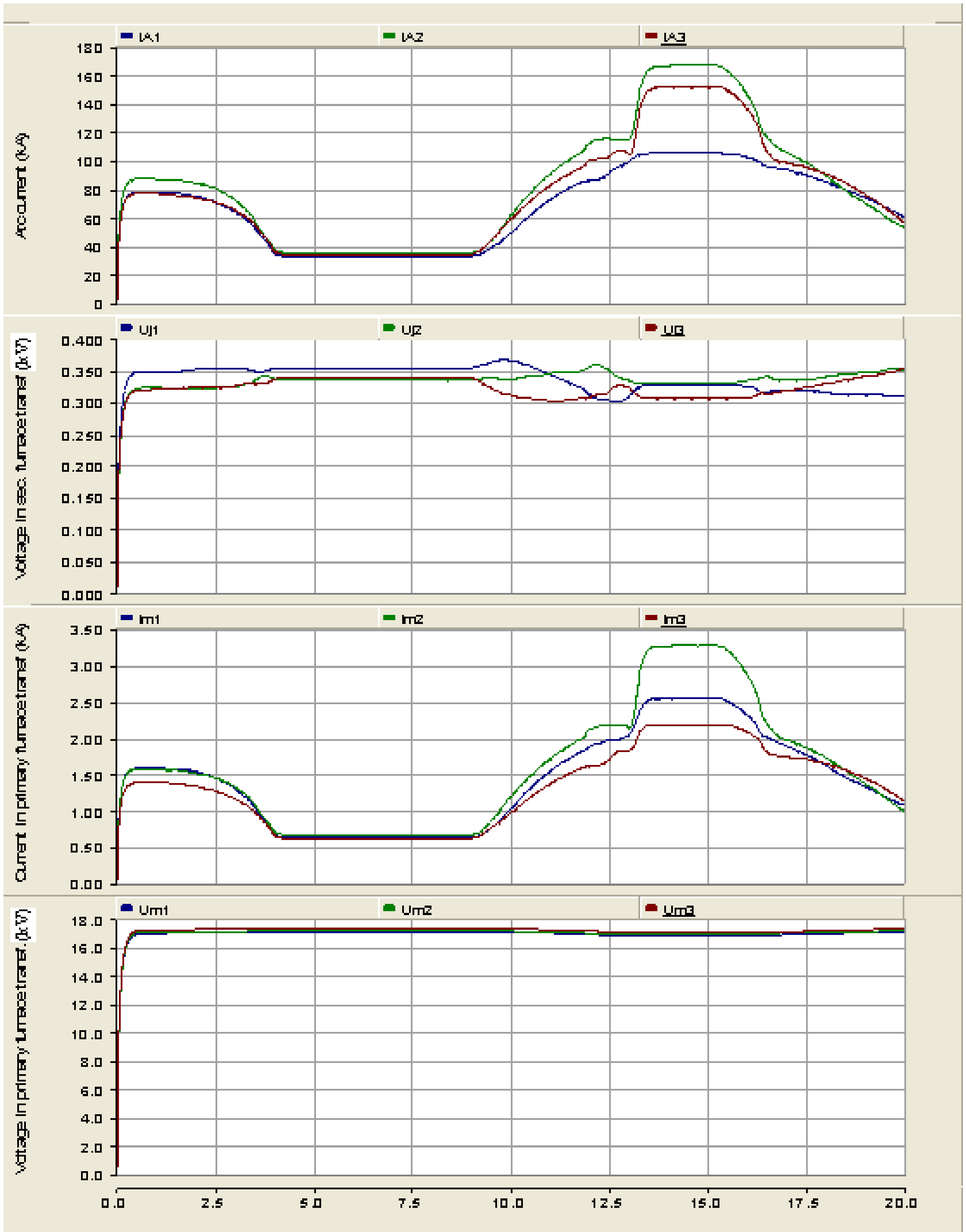


Fig. 2.2.25. The rms values for currents and voltages in the secondary and in primary windings of the transformer

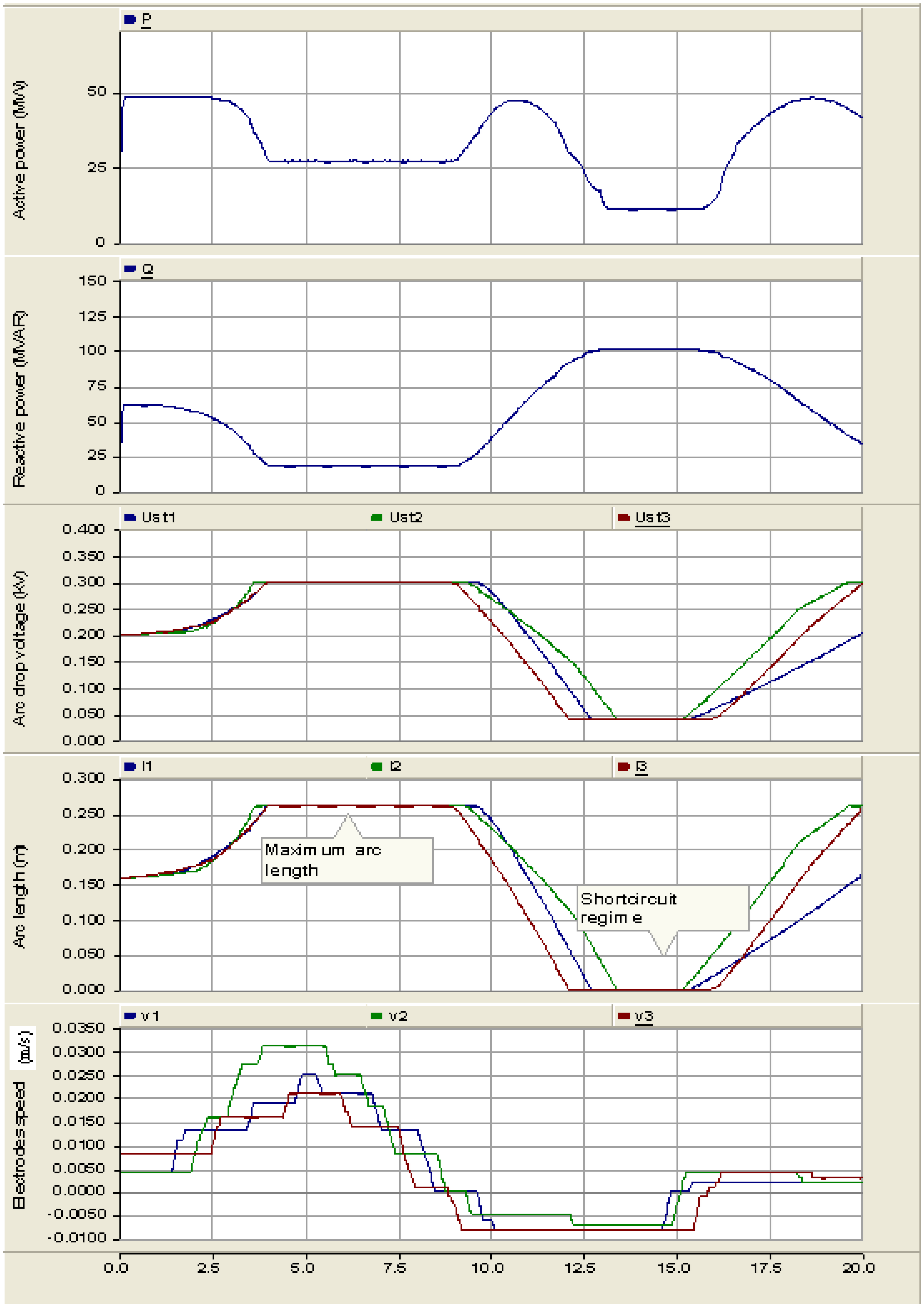


Fig. 2.2.26. The variation of active and reactive power, drop voltage, arc length and electrodes speed

2.2.3. Control of the active power of the EAF

Active power is the issue that must be controlled in scope of reducing the time in which the melting charge is finished. Two methods have outlined in the candidate researches: first is the classical control method through arc impedance and the second is an adaptive control using the LMS algorithm.

2.2.3.1. Active power control based on impedance arc measurements

The method is based on impedance adjustment which can be implemented by changing the electrodes position, and in consequence the arc length

$$Z = \frac{U}{I} = const \tag{26}$$

The impedance control is used in the most of actual systems. The general control diagram is presented in figure 2.2.27.

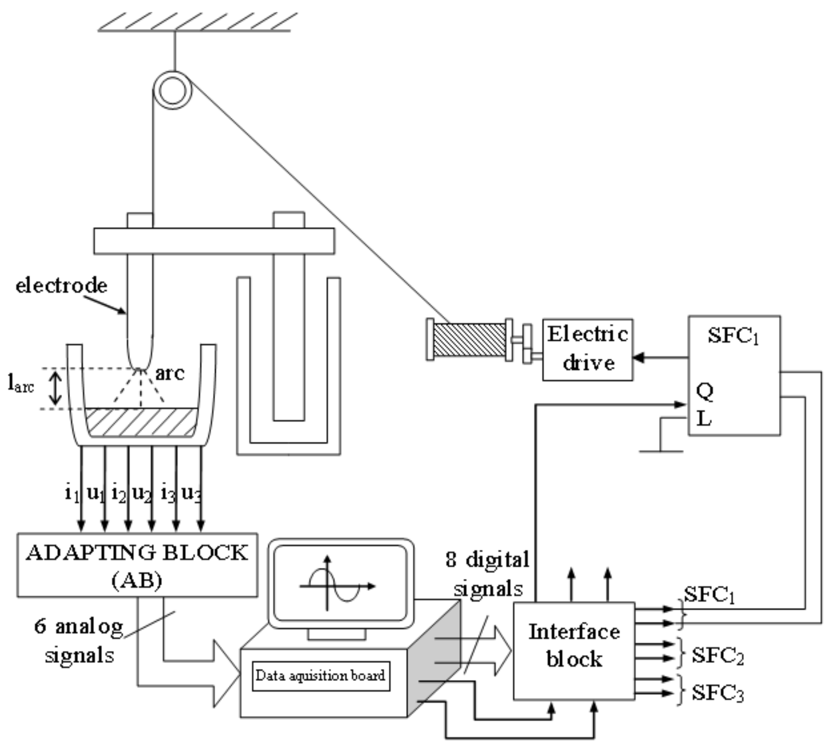


Fig. 2.2.27. The general control diagram

The values of the three currents and three voltages are aqquired by a data acquisition board, using an adapting block, AB. Relation (26) is used for computing the three impedances of electric arc of the each phase. Depending on the arc impedances each electrode can be commanded to move up (if $Z \leq Z_{opt} - Z_{risk}$), move down (if $Z \geq Z_{opt} + Z_{risk}$) or stop (if $Z_{opt} - Z_{risk} < Z < Z_{opt} + Z_{risk}$).

The least significant 6 digital output of data acquisition board command through an interface block the sense inputs of three static frequency converters (SFC), one of each phase.

The SFC are used to command the asynchronous electric drives which can move the electrodes using a speed reducer.

The proposed system functioning is based on an algorithm that is presented in figure 2.2.28.

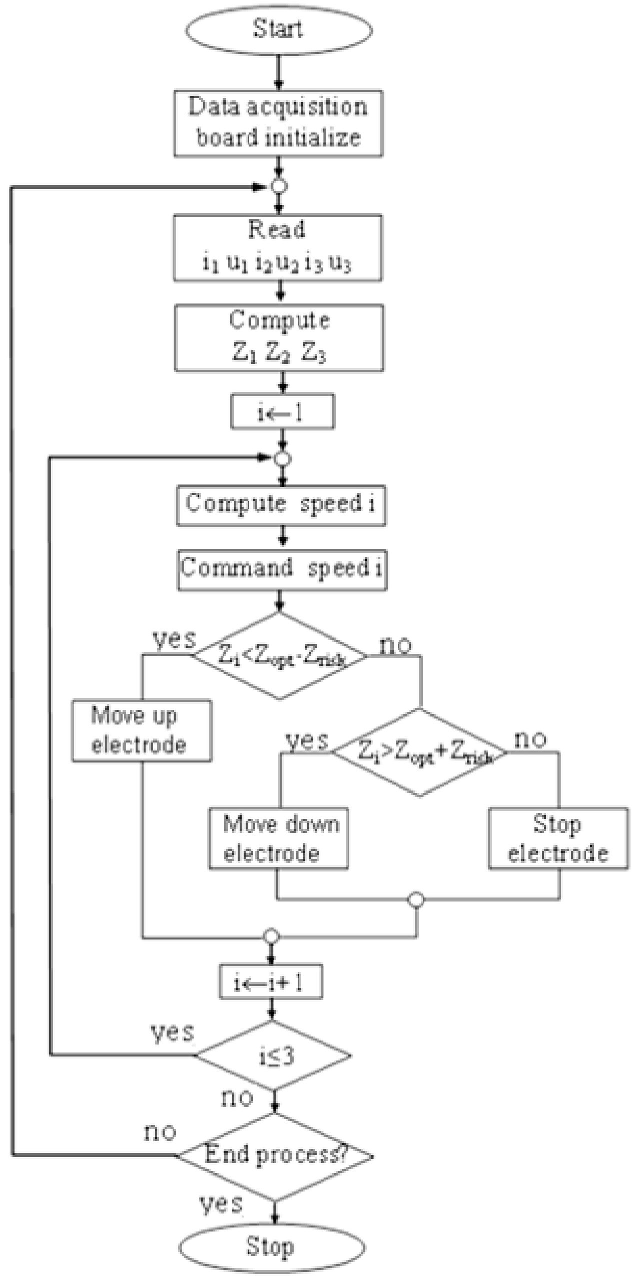


Fig.2.2.28 The control algorithm

The proposed method has the advantage that allows the on-line determination of the electric arc impedance. The estimated errors are low due to the resolution of the analog-numeric converter.

$$\varepsilon_r[\%] = 1/2^{12} \cdot 100 \approx 0.025\% \qquad (27)$$

Another advantage of the proposed method consists in using of static frequency converters that allows the elimination of electromagnetic coupling used at control of electric drive – reductor movement. This electromagnetic coupling makes a difficult maintenance due to the reduced reliability. Using the adequate command (through computer program) the speed control from minimum to maximum value in 256 steps can be obtained, that is matching to an imposed speed error of:

$$\varepsilon_r[\%] = 1/2^8 \cdot 100 \approx 0.4\% \tag{28}$$

The reliability of the static frequency converters eliminates the necessity of using supplementary protection diagrams at increasing the nominal values of currents and voltages.

The adaptive control method of the electrode motion control at EAF which is using a numeric system has many advantages in the field of system reliability, working speed and estimating errors.

2.2.3.2. Active Power Control using LMS Algorithm

Since the drop voltage depends linearly by the length of the electric arc, it results that also the active power depends on the length of electric arc.

Based on these remarks, the proposed iterative control algorithm of the active power is based on the modification of the length of electric arc, depending on the active power desired to be obtained.

The LMS algorithm used for active power control

Assuming that at iteration *n* the length of the electric arc is *l(n)* and the active power is *P(n)*, the length of arc at *n+1* iteration will be given by the relation

$$l(n+1) = l(n) + \alpha \cdot e(n), \tag{29}$$

where

$$e(n) = P_0 - P(n) \tag{30}$$

is the error by which the imposed active power P_0 at iteration *n* is obtained and α represents an adapting factor. This algorithm is known as the LMS algorithm (Least Mean Square) or the stochastic gradient algorithm, being, due to its simplicity, the most used algorithm implemented in the current systems. Choosing the value of the adapting factor is made taking into account its influence upon the main characteristics of the algorithm: the algorithm convergence speed and the adjustment error. Figure 2.2.29 shows the variation of the voltages, currents on the low and medium line, active power (imposed and obtained), reactive power, drop voltage and arc length.

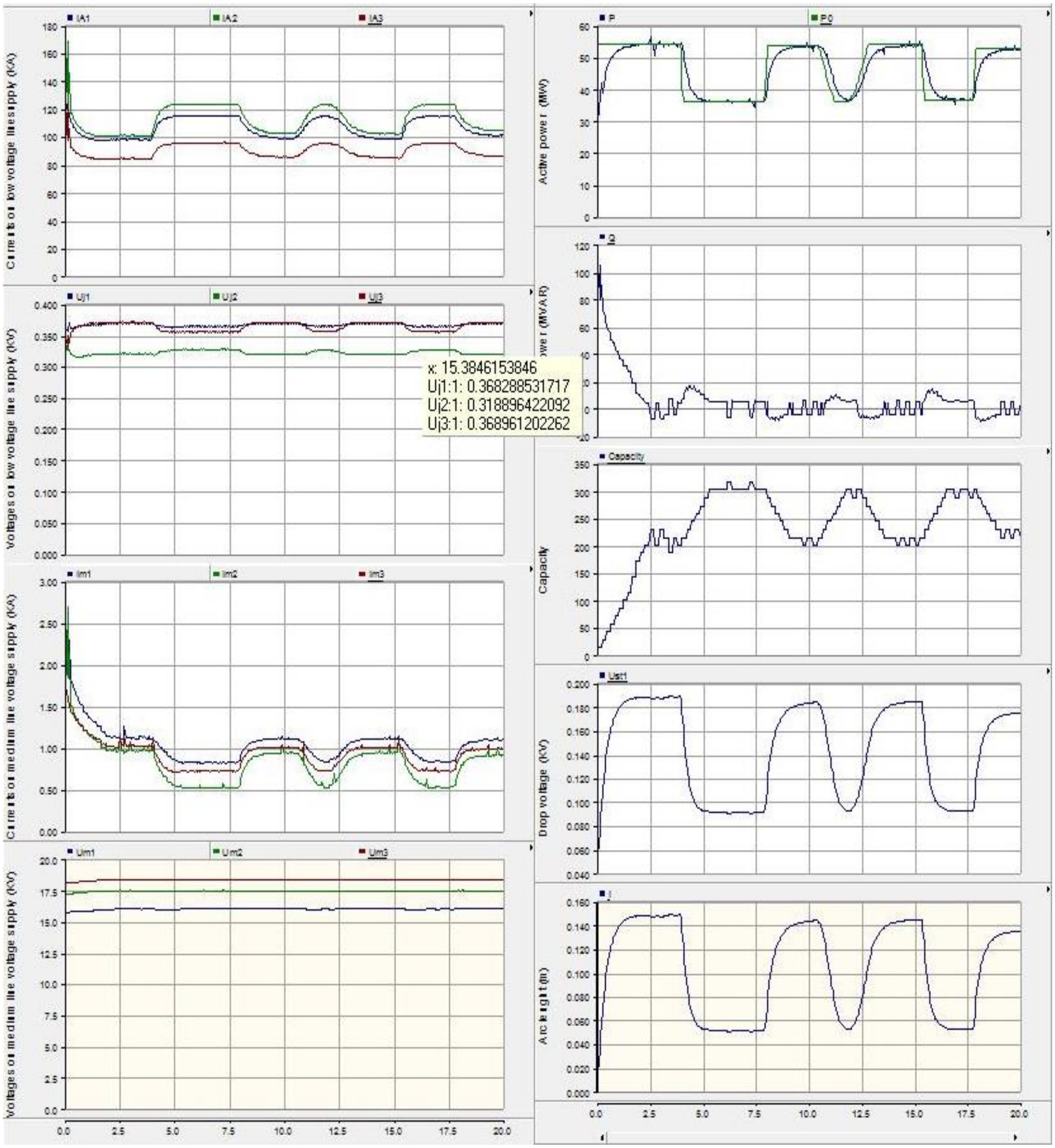


Fig. 2.2.29. The simulation results using standard LMS algorithm for controlling the active power.

The variable step LMS algorithm used for active power control

In relation (29), usually can note

$$\alpha = 2\mu , \tag{31}$$

where μ is a parameter that influence the convergence and the error of the algorithm.

The factor μ can take values between a minimum and a maximum value, depending on errors and on the values which assure the convergence of the algorithm. There are two methods used for variation of μ:

a) The first method, namely VS, permitted the increasing value of μ by multiplying with a factor $\alpha' > 1$, respectively decreasing the value of μ by dividing with the same factor α'.

$$\mu_i(n) = \mu_i(n-1) \cdot \alpha' \quad or \qquad \mu_i(n) = \mu_i(n-1)/\alpha' \tag{32}$$

b) The second method, namely VSA, permitted the increasing value of μ by adding a constant $\alpha' > 0$, respectively decreasing the value of μ by subtracting the same constant value α'.

$$\mu_i(n) = \mu_i(n-1) + \alpha' \ or \qquad \mu_i(n) = \mu_i(n-1) - \alpha' \tag{33}$$

Both VS and VSA method are implemented by the algorithm from figure 2.2.30.

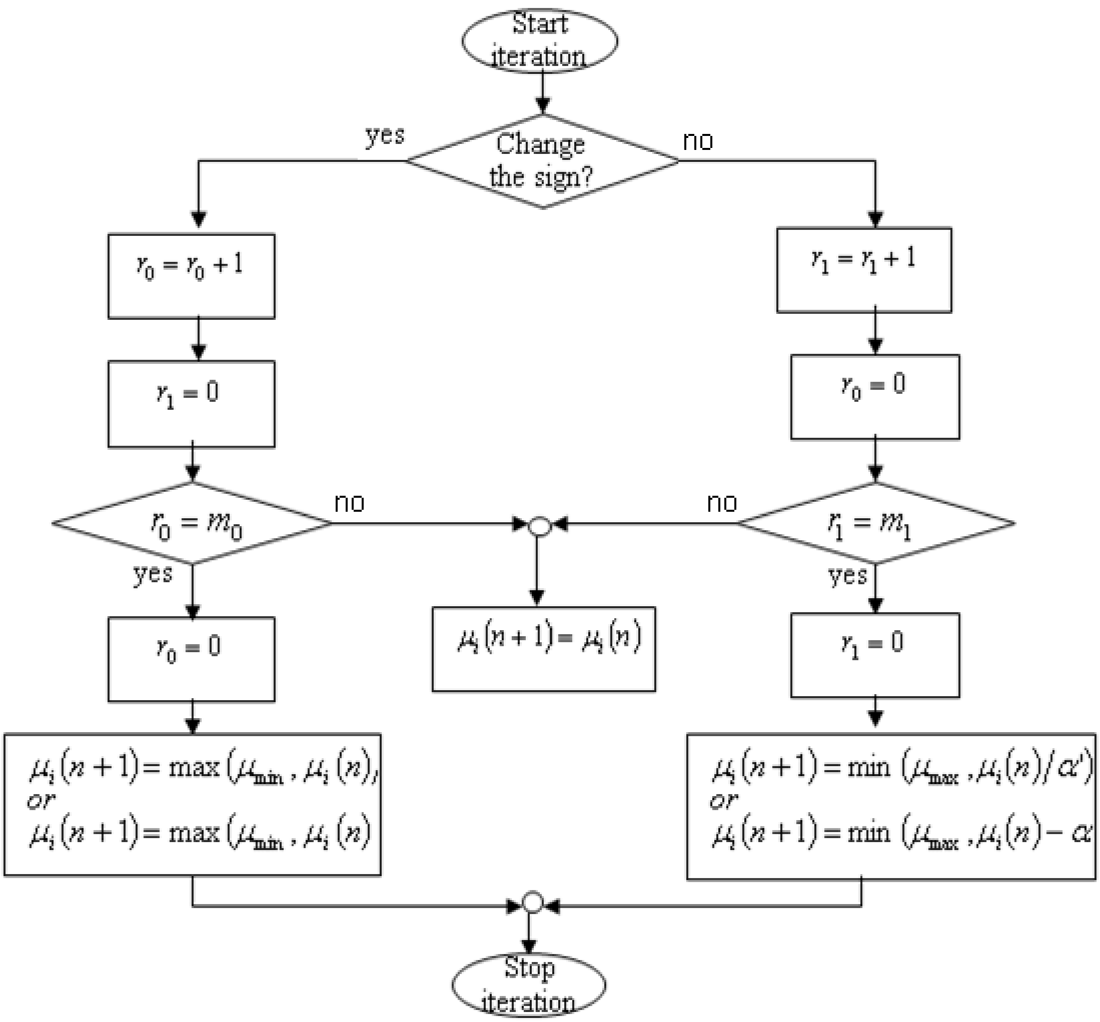


Fig. 2.2.30. The VS and VSA algorithm for computing of parameter

In figure 2.2.30 , m_0 is a parameter which determines a decreasing of μ after m_0 consecutive changes of the sign of *e(n)* and m_1 is a parameter which determines an increasing of μ after m_1 consecutive no changes of the sign of *e(n).* The number of consecutive changes and no changes of *e(n)* are determined using the parameters r_0 and r_1 irrespectively.

The simulation results using this method are show in figure 2.2.31.

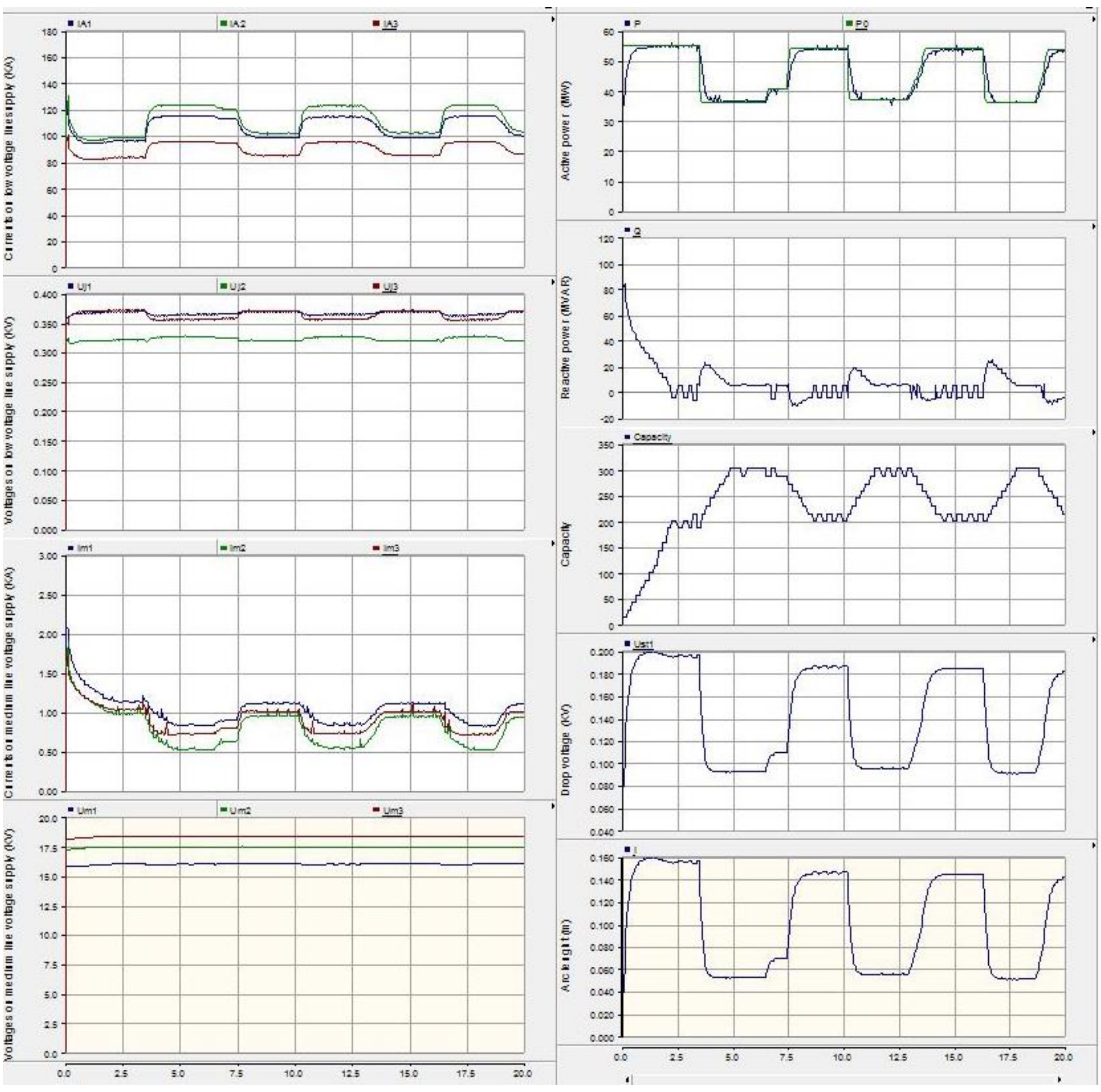


Fig. 2.2.31 The simulation results using VS algorithm for controlling the active power

The simulations have been made using $\mu = 0.000005$, m_0=m_1=10, and $\alpha' = 1.5$. The values of m_0, m_1 and α' were chosen by testing the algorithm behaviour in different conditions. Comparing the results from figures 2.2.29 and 2.2.31 the most important observation consists in the fact that the convergence speed of VS algorithm is greater than the convergence speed of LMS algorithm, in condition in which the algorithm convergence is assured.

The PSCAD-EMTDC simulation scheme for VS method is depicted in figure 2.2.32.

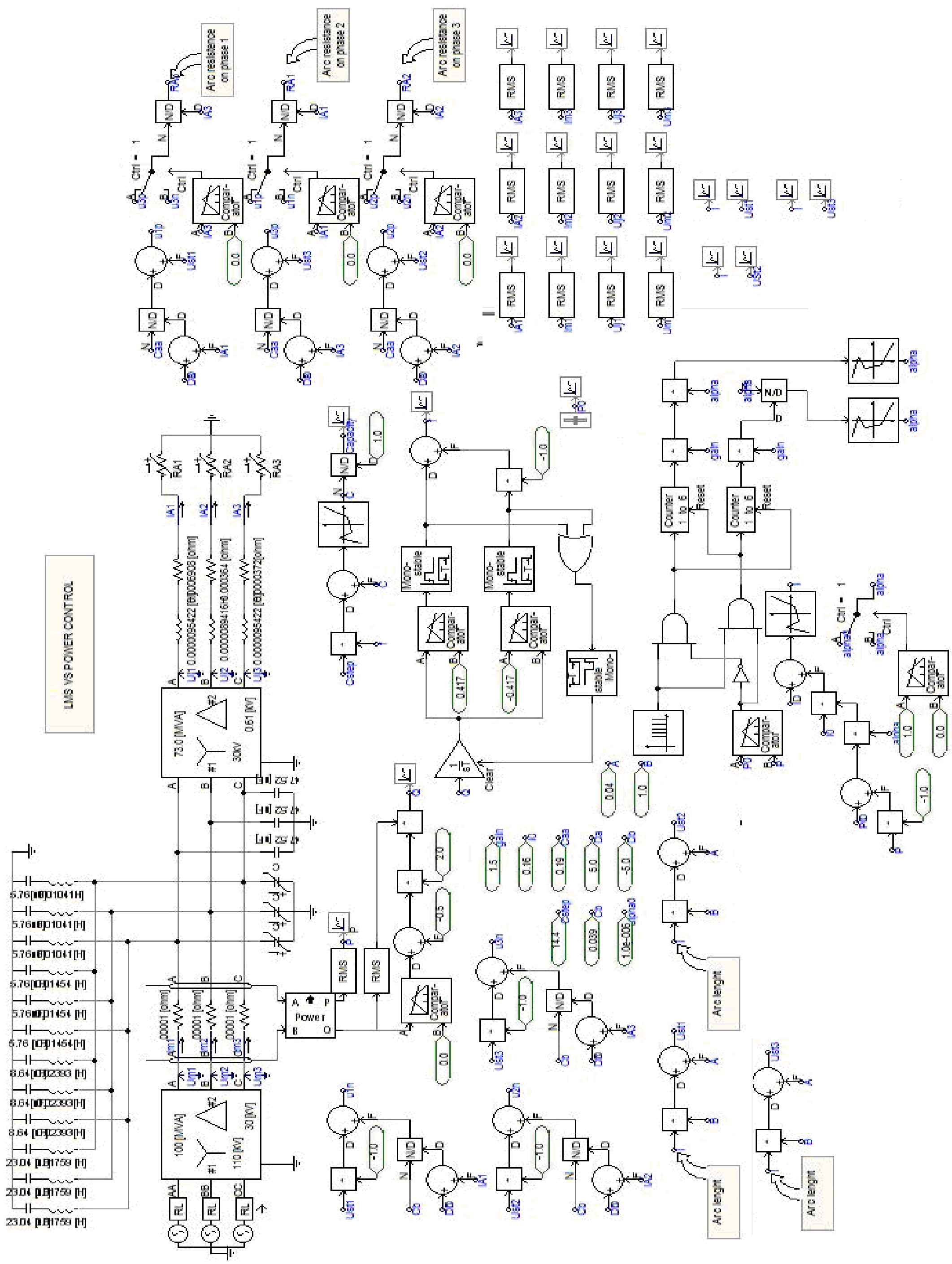


Fig. 2.2.32. The PSCAD-EMTDC simulation scheme for VS method

It was observed that for higher values of the adapting factor it was obtained a higher convergence speed of the control algorithm, but the dispersion obtained around the desired value is higher, the algorithm being possible to lose his convergence. Smaller values of the adapting factor allow the obtaining of a smaller dispersion of the values of the system output, but the convergence speed is also smaller.

In conclusion, using a variable step algorithm, the speed control of the active power can be improved, but the consequence is an increasing of the number of computing operations. This means that this algorithm is recommended to be used when the processes are not so fast regarding to computer system speed, which is the case in our process of active power control.

2.2.4. Research regarding simulation of the flicker effect based on modeling the electric arc

An arc furnace is probably the load that produces most pronounced flicker effect ([Islam 12], [Anuradha 08], [Zhang 01], [Sousa 99], [Tang 97], [Mendis 96], [Petersen 95] and [Montanari 94]). When the arc furnace operates, an unstable arc will appear between the electrodes and the scrap, resulting a fluctuating power consumption and thereby a potential flicker problem. As a rule of thumb the ratio between the short-circuit capacity at the point of common coupling (PCC) to the maximum demand of the arc furnace should be greater than 80 in order to limit the risk of flicker caused by the arc furnace. The mitigation methods are quite expensive and discussions between the network operator and the owner of the arc furnace regarding cost sharing are common.

The author did some research based on modeling the electric arc that allowed simulation of flicker effect. The results of this research have been published in [Pănoiu M 08e], [Pănoiu M 08h].

The quick variations of the voltage absorbed by the electric furnace arc during the melting process are closely dependent on the variations of the electric arc length, caused by the position changing of the metal pieces and the variation of the electrodes positions. At present, two approaches have been developed as to the variation pattern of the electric arc length, the former supposing a determinist approach and the latter, a statistical one.

According to the determinist variation it is considered that the electric arc length has a time-dependent variation pattern that can be described by a sinus law. The time-dependency of anode voltage can be obtained considering that the arc length is changing according to relation

$$l(t) = l_0 - \frac{L}{2}(1 + \sin \omega t), \tag{34}$$

where L represents the maximal variation of the electric arc length (the electrode movement range) and l_0 is the maximal length of the electric arc (the maximal distance between the electrode and the metal bath). Using relations (22), (23), (24) and (34) one can obtain the time variation of the dependency $U_A(I_A)$, in relation (34):

$$V_A(I_A) = 1 - \frac{B \cdot L/2 \cdot (1 + \sin \omega t)}{A + B \cdot l_0} \cdot V_{A0}(I_A) \quad (35)$$

By using the notation

$$m = \frac{L}{2l_0 - L},$$

can be noticed that for $L = 0$ it is obtained $m = 0$, and for $L = l_0$ it is obtained $m = 1$, parameter m representing the modulation index of the electric arc length. The model implemented in PSCAD-EMTDC is depicted in figure 2.2.33.

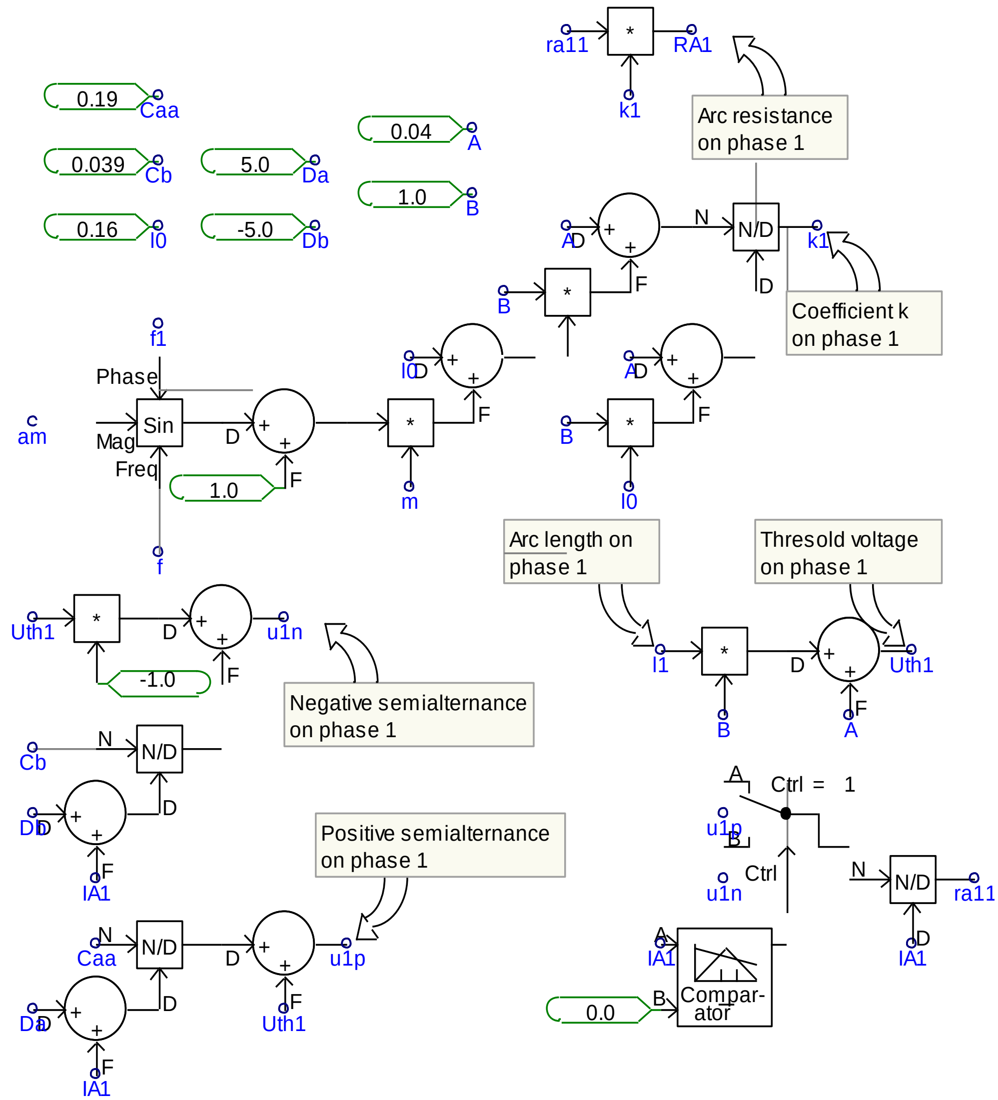


Fig. 2.2.33. The electric arc model for flicker simulation implemented in PSCAD-EMTDC

By simulation whith this model, the arc current and arc voltage waveforms shown in figure 2.2.34 were obtained. The influence of the modulation index can be observed in figure 2.2.35 where the variation of the arc voltage and the signal spectrum for $m=0.2$ (red) and for $m=0.6$ (blue) is presented. For the modulation frequency the value 10 Hz was chosen. For this value is the most probable to appear flicker phenomena [Montanari 94]. It can be observed in figure 2.2.34 that the maximum value of the current envelope corresponds to the minimum value of the voltage envelope, as results from (21).

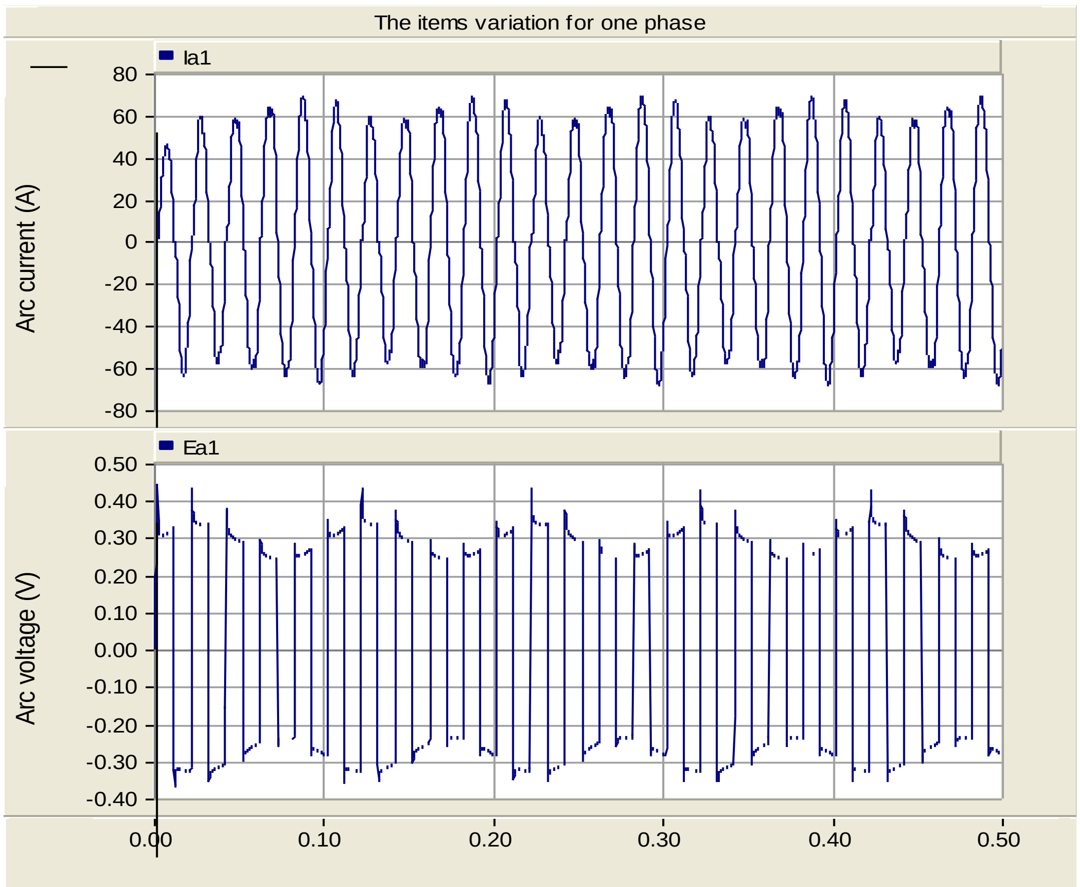


Fig. 2.2.34. The waveforms for arc current and voltage $m=0.4$

Another way to simulate the effect of flicker produced by electric arc furnaces is based on the model presented in section 2.2.1.2. A.

For the simulation of the flicker phenomenon, the variation of the electric arc characteristic was necessary to obtain, and this was realized by imposing a variation for one parameter of the model. Some parameters are conditioned by it. The variable chosen parameter is R_1. Taking into consideration that the ignition voltage, extinction voltage (drop voltage) and the power of the electric arc are constants, using the relation (12), it can be computed in every moment the value of R_2. In this way, the voltage - current characteristic of the electric is variable, and its variation depends on the R_1 parameter variation law.

For an accurate implementation of this model, the following conditions must be accomplished: during the implementation of the dynamic model is necessary to ensure constantly the value of the R_1 parameter for at least a half cycle of the supply voltage. This demand must be accomplished for realizing of the voltage – current characteristic for any value of the simulated current and voltage, considering as reference the same time interval. The variation of the R_1 parameter in every half cycle of the supply voltage ensures the unsymmetrical current and voltage of the electric arc, an important characteristic of the electric arc furnace. Another condition is given by the variation of the R_1 parameter that has to ensure a constant value of its medium value, in order to maintain constant the power of the electric arc.

From relation (36) it can be observed that the medium value of the $R_1(t)$ parameter is equal to R_1, so the medium power of the electric arc is constant.

There were developed two directions for the R_1 parameter variation: a determinist variation and statistical variation.

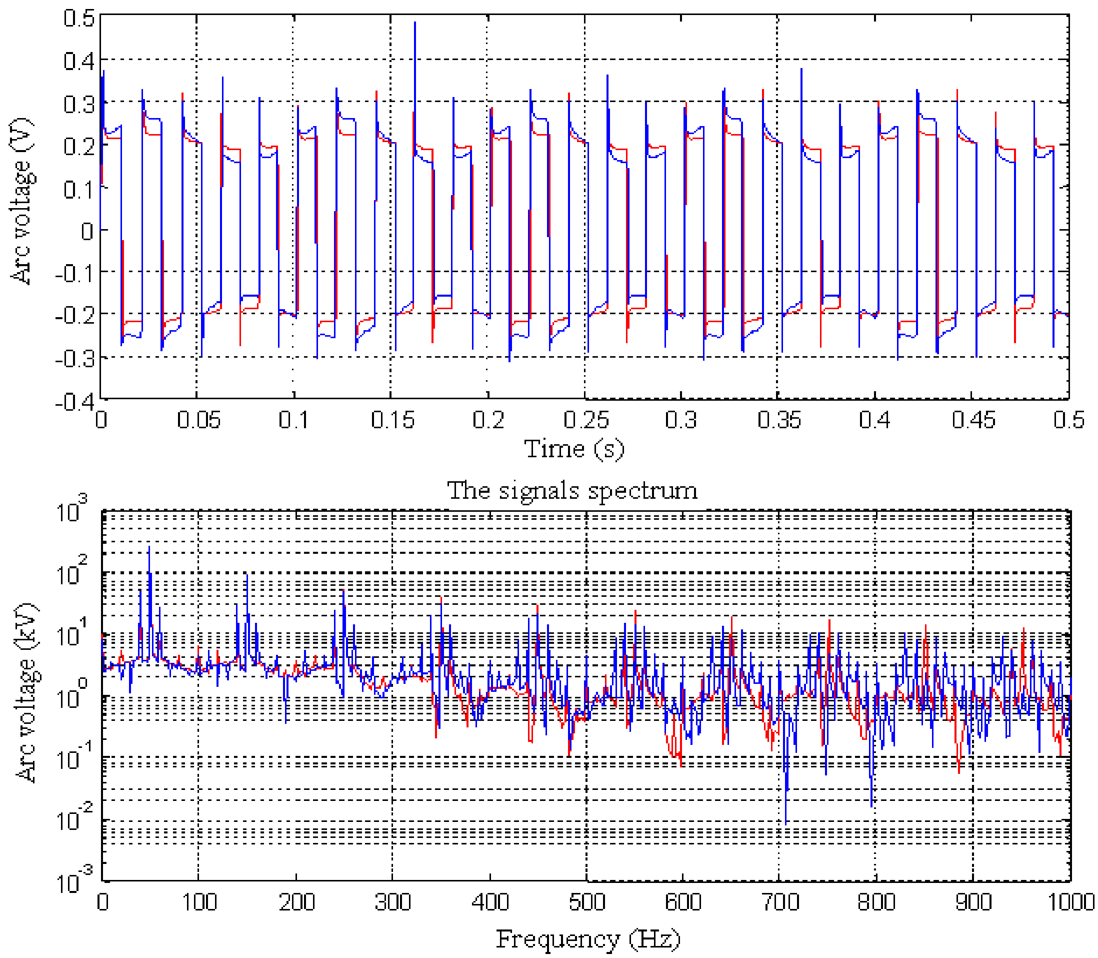


Fig. 2.2.35. The waveforms for arc voltage and the signals spectrum for $m=0.2$ (red) and $m=0.6$ (blue)

2.2.4.1. The sinusoidal variation of the parameter R_1

The determinist variation presumes that the R_1 parameter describes a sinusoidal variation. The time dependence of the R_1 parameter can be obtain taking into consideration that is has variation according to the relation:

$$R_1(t) = R_1 \cdot (1 + m \cdot \sin 2\pi f_0 t)\,, \tag{36}$$

where f_0 is the variation frequency of the R_1 parameter and m is the modulation index. For the simulation of the flicker phenomenon, f_0 has a value in the frequency domain where this phenomenon appears. The simulation scheme implemented in PSCAD-EMTDC is depicted in figure 2.2.36.

The simulations are permitting to obtain the waveforms of the current and voltage of the electric arc and the value of the R_1 parameter presented in figure 2.2.37. In these simulations, the modulation frequency is *10Hz* and the modulation index is *m=0.5.*

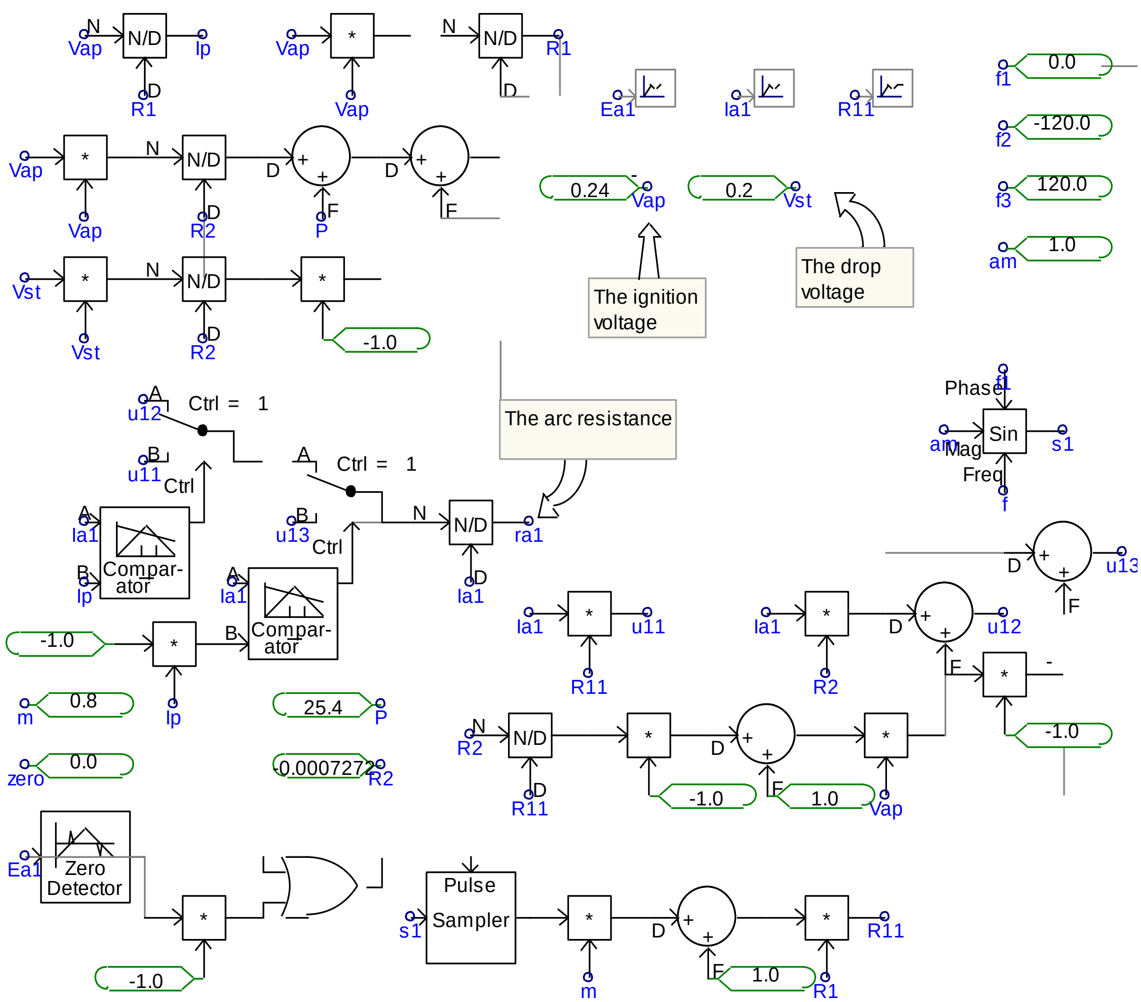


Fig. 2.2.36. The model implemented in PSCAD-EMTDC for sinusoidal variation of the parameter R_1

2.2.4.2. The random variation of the parameter R_1

The statistic variation presumes that the variation of the parameter R_1 has a variation described by white noise law with a limited band.

In this case the time dependence of the parameter R_1 can be obtained according the relation:

$$R_1(t) = R_1 + r(t), \tag{37}$$

where *r(t)* represents a zero media white noise and a limited frequency band signal.

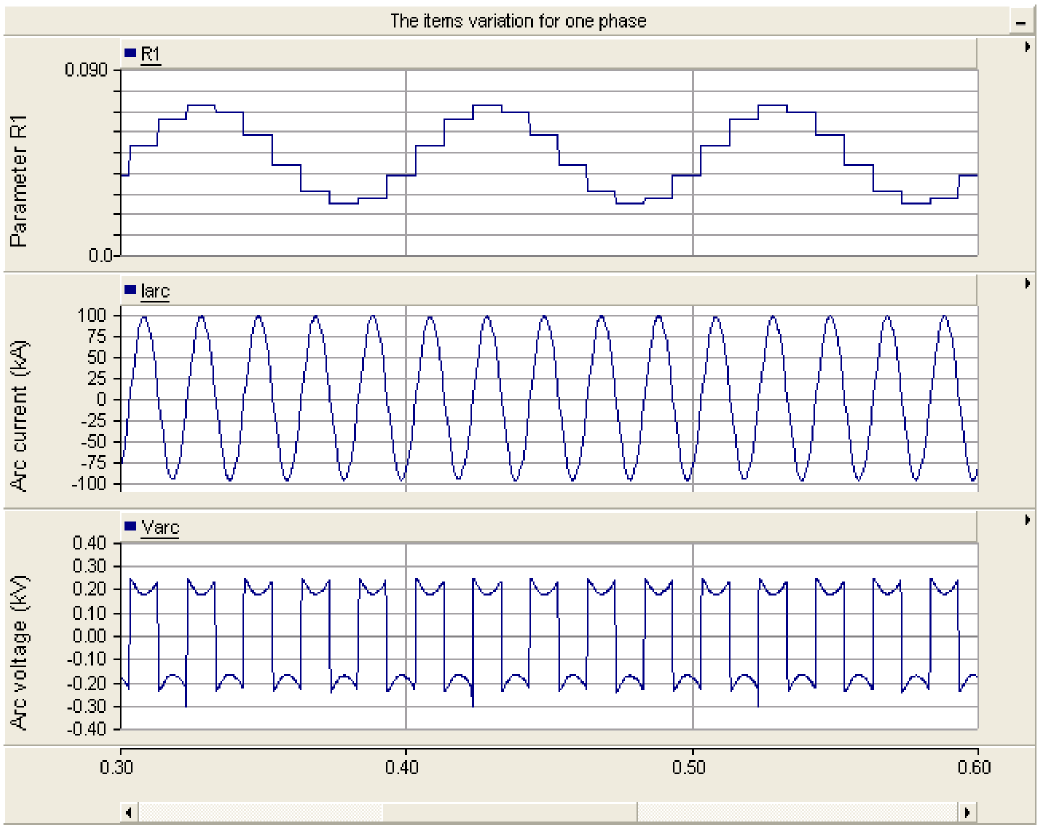


Fig. 2.2.37. The waveforms for arc current and voltage and the variation of R_1 for *m=0.5*

Like in the previous cases, the frequency band is chosen in the frequency domain where the flicker phenomenon appears. The figure 2.2.38 represents the current and voltage of the electric arc variation form and the variation of the parameter R_1 using the modulation index *m=0.6.*

The measurements were made at a 3-phase power supply installation of a 3-phase EAF of 100t, to which the harmonics filters were not connected. Comparing the simulating spectral characteristic with the measured spectrum (for the medium voltage line feed) it can be found the presence of the same harmonics and interharmonics, as in figures 2.2.39 and 2.2.40 [Pănoiu M 08e], [Pănoiu M 08h].

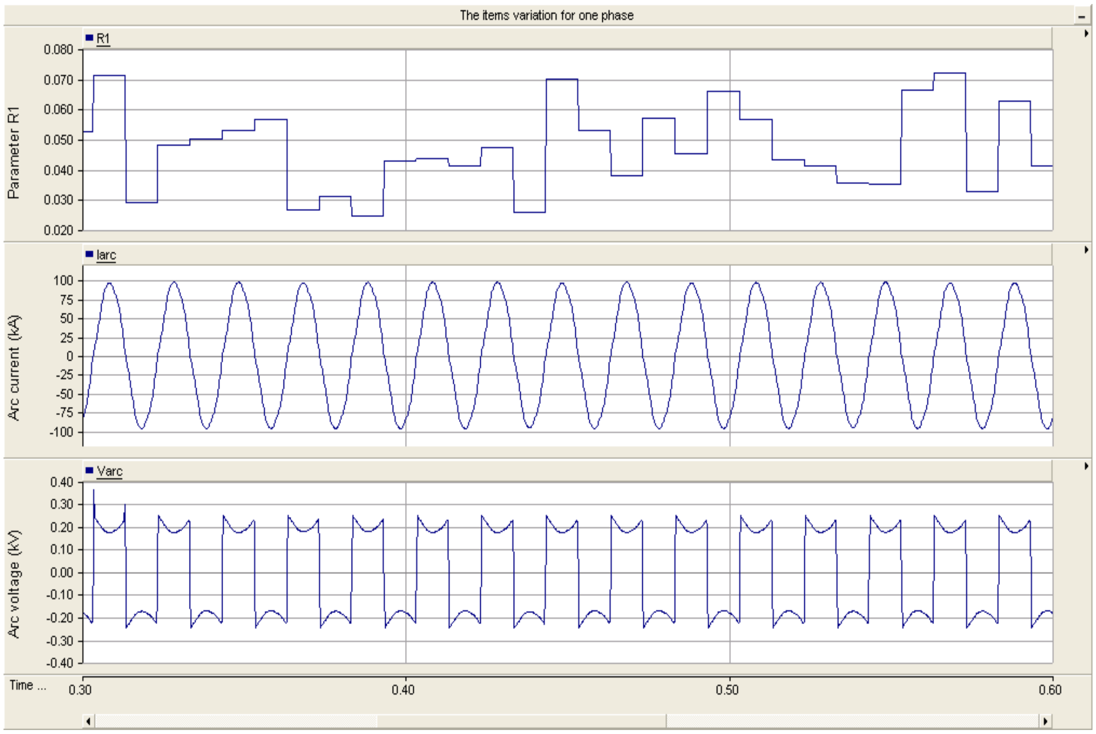


Fig. 2.2.38. The waveforms for arc current and voltage and the variation of R_1 for $m=0.5$

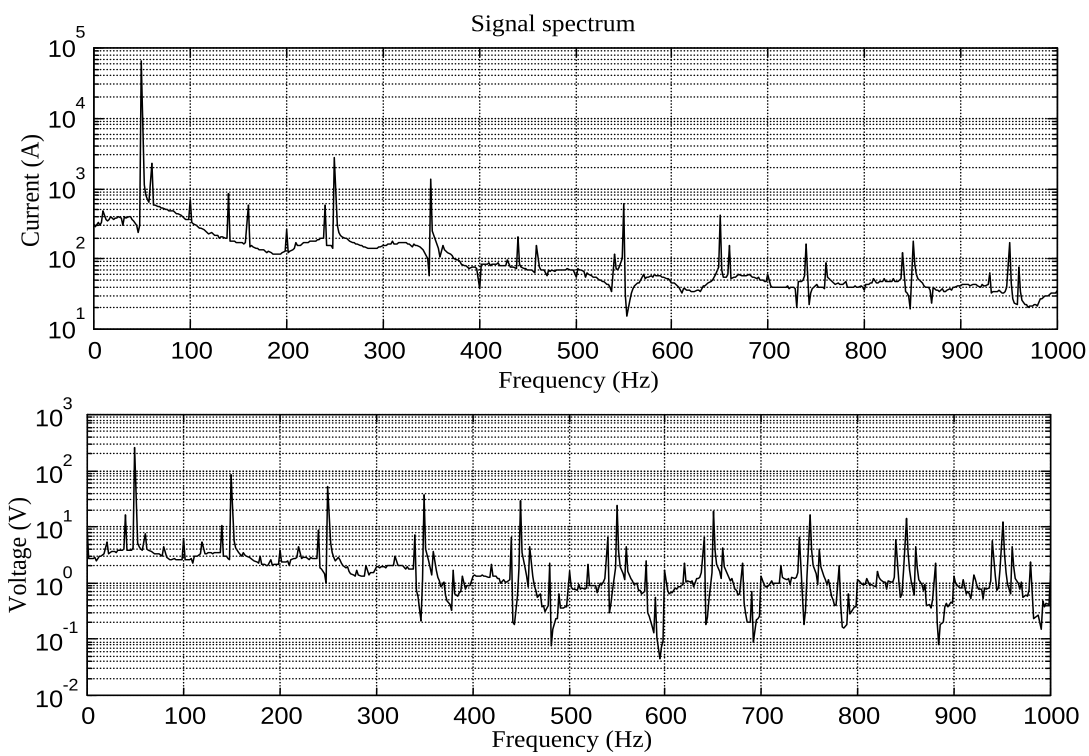


Fig. 2.2.39. The signals spectrum for current and voltage for sinusoidal variation of the parameter R_1 and m=0.2

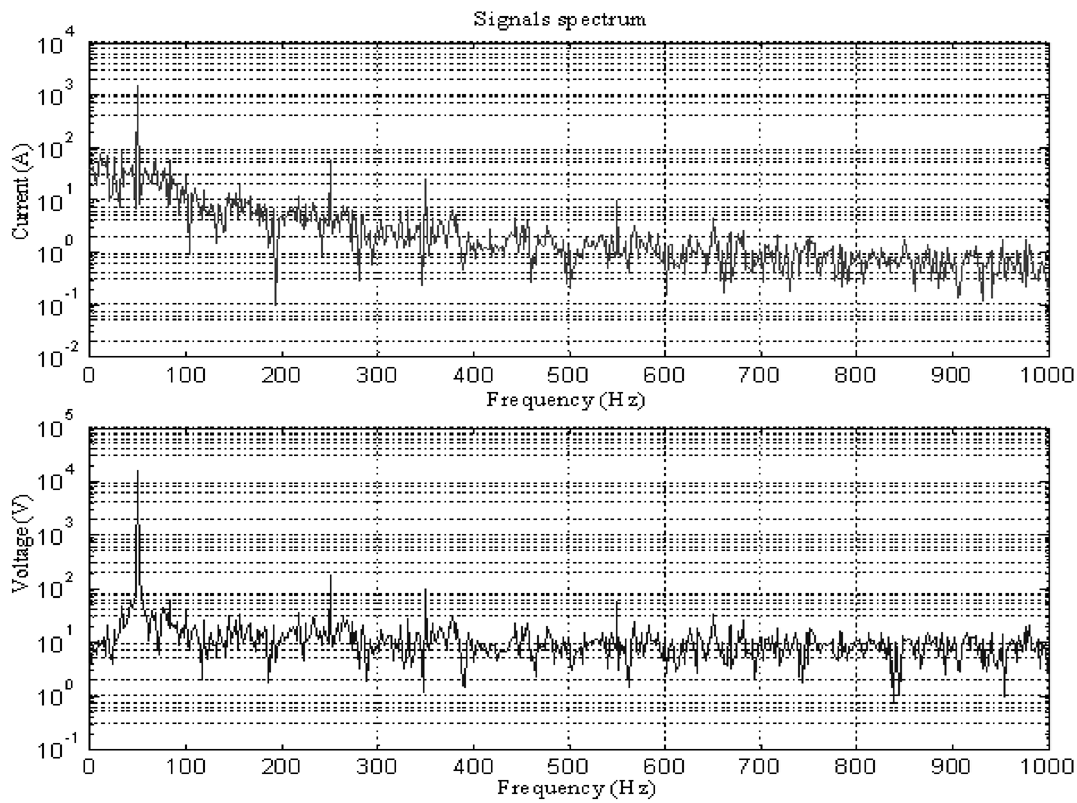


Fig. 2.2.40. The signals spectrum for current and voltage for random variation of the parameter R_1 and m=0.2

2.2.5. Other research based on modeling, identification and simulation in electrical engineering

In the material presented in this chapter, the candidate was the principal researcher. Besides these researches, candidate participated as a member of research teams from other research topics, which will be briefly presented further.

2.2.5.1. Algorithms and methods for adaptive signal processing

Candidate was part of a research team focused on the adaptive filters, [Pănoiu C 07a], [Pănoiu C 08b], [Pănoiu C 08c], [Pănoiu C 08d].

One of the most common problems in using of adaptive filters is their behavior in condition of application of a high amplitude and short time pulses at the filters input. The ALMS filter is an OSLMS filter, featured by a good convergence of their coefficients into optimal values, but a low stability of the prediction coefficients. Another OSLMS filter is the MLMS filter, featured by greater prediction coefficients stability, but a lower coefficients convergence to the optimal values.

In [Pănoiu C 07] a new filter which has the both filters advantages is presented, by using a weight coefficient for the two kinds of filters. This filter uses a parameter to detect the presence or absence of an impulse in the data window. Depending of the decision taken, the algorithm switches between the application of algorithm MLMS, if the impulse is considered to be inside the window, or of algorithm ALMS if no impulse is detected and more than that depending on the amplitude of impulse the weight of the two filters is chosen.

The properties of three algorithms (gradient algorithm, SHARF algorithm and Steiglitz-Mc Bride algorithm) are studied in [Pănoiu C 08d], by computing the IIR filters coefficients. It was studied three kind of IIR filters (IIR, Average-IIR and Median-IIR) implemented in direct form and in lattice form.

In [Pănoiu C 08b], the authors present a real time identification of the parameters value of a slow process. This kind of process can be assimilated to process with a time constant and a delayed time. The parameters are identified by using an adaptive algorithm. The initial values of the parameters can be computed using an on-line identification method and they are necessary to ensure the convergence of the adaptive algorithm.

Paper [Pănoiu C 08c] is an extended version of [Pănoiu C 08b] and presents a real time identification of the parameters value of a slow process using adaptive IIR-OSLMS filters. The initial values of the parameters can be computed using an on-line identification method, in order to ensure the convergence of the adaptive algorithm. The measured temperature is affected by noise, so it was used an ALMS filter to reject the noise.

2.2.5.2. Modeling and simulation of inductive installations functioning

The paper [Rob 09a] presents a study regarding the functioning of a melting/hardening electrothermal installation with electromagnetic induction from the point of view of generated harmonics in the supply system. Simulations were made in scope of study the possibility of reducing the effects of the generated non-sinusoidal regime. The paper [Rob 10c] describes a modern method for reducing the harmonic distortion induced by electro thermal installation at the PCC by injection a current equal in magnitude but in opposite phase to harmonic currents, in order to achieve a sinusoidal current wave in phase with the supplying voltage. The authors modeled a simplified active filter in parallel configuration in scope of reducing the effects of the generated non-sinusoidal regime. Modeling and simulation were made using PSCAD EMTDC tool.

In scope of studying the distorted regime parameters generated by three phase nonlinear loads, [Pănoiu C 12a] presents a measuring system that uses LabVIEW. Using a data acquisition board connected to a computer, the proposed system can acquire distorted and unbalanced current and voltage signals and processes them by a LabVIEW application in order to display the variation of the specified parameters. This measuring system permits for the electrical parameters to be observed in real time, being very important in studying the nonlinear loads functioning. In other paper, [Pănoiu C 11a], a study about the command of an active filter with IGBT transistors using a data acquisition board is presents. The main purpose of this active filter is to reduce the harmonic distortion in power distribution generated by an electro thermal installation with electromagnetic induction. IGBT transistors are controlled using a command scheme designed in LabVIEW. In [Pănoiu C 11c] the way about the command of the active filter with IGBT transistors is shown.

2.2.5.3. Research regarding Simulating the Electromagnetic Field in a Multimode Microwave Oven

Another research theme conducted by candidate as member in a research team was presented in [Abrudean 09a] and [Abrudean 11]. The paper [Abrudean 09a] shows the results of simulation for the electromagnetic field of the multimodal microwave oven. It was implemented a simulation program based on the finite difference time-domain method. The simulation program was implemented in C++, is multithreaded and optimized for use on multicore/multiprocessor platforms.
Classical numerical methods for electric heating processes involve the use of temperature as a state variable. These methods become difficult when the process contains isothermal or nearly isothermal phase changes, as we must simulate several systems and their interactions within mobile phase change fronts. [Abrudean 09a] describes an adaptation of the classical finite difference method which eliminates these disadvantages. This model uses three interdependent state variables for each node of the mesh: temperature, enthalpy and a reduced temperature which includes the variation of thermal conductivity with temperature. The model requires knowledge of the enthalpy temperature dependence (which includes specific and latent heats) and the thermal conductivity temperature dependence throughout the temperature range studied. The paper contains results of relevant numerical experiments and an analysis of the running time dependency on the number of mesh nodes and the number of processors in a parallel computer.

2.2.5.4. Simulation models of behavior of magnetodielectric materials based on powders in magnetic field of radiofrequency

In the computational analysis of nano-particle magnetic media, usually periodic models for nano-particle disposal are involved. These models, for lower computational costs, assume that the material has a deterministic and ordered distribution of nano-particles. However, real nano-structured magnetic media show non-uniformly distribution of nano-particles. A very important aspect related to the behaviour of a magnetic nano-particle system is represented by the effect of the dipolar magnetic interactions. For simulating this effect, it is extremely important to generate the positional structure of the nano-particles in a given quantity, at a given concentration. [Osaci 09] presents a model of non-uniformly 3D arrangement of the nano-particles that belong to a nano-structured magnetic media. The model can be easily integrated in the category of static and dynamic behaviour of the magnetic nano-particle systems.

[Osaci 06] presents the results obtained by numerical simulations, the magnetic relaxation time simulation for a fine particle system with dipolar magnetic interaction. The authors used a 3D simulation model for fine magnetic particles with spherical shape and lognormal distribution for their diameters. Starting from Dormann-Bessais-Fiorani model, a 3D model, is more realistic if is considered that the particles are randomly arranged into a preset volume, following a Gaussian distribution generated with the Box-Mueller transformation. Concerning the dependency of the average relaxation time on temperature and on the dispersion logarithm of the particle diameters, the analysis is achieved for three cases: without interaction, weak dipolar magnetic interaction and strong dipolar magnetic interaction between particles.

[Osaci 06] presents an improved simulation method, which permits to study the influence of the electromagnetic high frequency fields on the properties of magnetodielectrical materials. The proposed method can be used, for example, to simulate the dependency on the frequency of bulk magnetic permeability by using the dependence on the frequency of the powder magnetic permeability.

2.3. CONTRIBUTION TO ARTIFICIAL INTELLIGENCE FIELD IN ELECTRICAL ENGINEERING

After graduation of PhD stage, the computational intelligence was one of the main themes of candidate research. In this domain, the candidate paid attention to fuzzy logic systems and neuronal networks.

2.3.1. Electric arc modeling using neural networks

One of the applications of artificial neuronal networks was the modeling of the electric arc, presented in previous chapter. Taking into account the various applications of the artificial neuronal networks over the nonlinear and complex problems, there is the possibility of modeling the electric arc using artificial neuronal networks, [Pănoiu M 13b] şi [Pănoiu M 13d].

In the past years, ANNs have been used to model complex systems for which analytical mathematical models cannot by defined precisely. The EAF is a system that involves complex and multi-variable process with time-variable parameters. So, for an EAF modeling ANNs are suitable ([Sadeghian 11], [Chang 10], [Sadeghian 00], [Sadeghian 99a], [Sadeghian 99b], [Hui 09], [King 96]). In order to develop a model based ANN, actual recorded data from the electrical installation of an EAF are necessary. These data are obtained by voltages and currents measured in the secondary furnace transformer of an EAF with the capacity of 100 tones ([Pănoiu M 07g] and [Pănoiu M 06c]). The frequency acquisition was 5 kHz. These data have been used for ANNs training. Model validation used a set of measured data from the first stage of the melting process, i.e. the meltdown stage, because in this stage the currents and the voltages are more distorted. In figure 2.3.1 and 2.3.2 the time variation of voltages and currents for all three phases for melting and refining stage are shown [Pănoiu M 07c].

2.3.1.1. Model based on feedforward artificial neural networks

A MLP (Multi-Layer-Perceptron) ANN is a feedforward neural network with one input layer, one output layer and one of more hidden layers. The model inputs and outputs and the hidden layer provide the learning capability of the EAF model.

Neural network architecture affects performance of electric arc modeling. Several tests with MLP ANN were made in the training process. For this, the learning rate and the number of neurons in the hidden layer were modified. So, it can be observed from figure 2.3.3.a, 2.3.3.b and 2.3.3c the training performance, the validation performance and the testing performance depend on the learning rate and on the network architecture, i. e. the hidden neurons. The learning rate was varied between 0.05 and 2 and the number of hidden neurons was varied between 50 and 150. It can be observed that the best results are obtained for a number of hidden neurons greater than 100. The training data set contain 625 samples from which 70 % was used for training, 15% for validation and 15% for testing. The data set is from the melting stage.

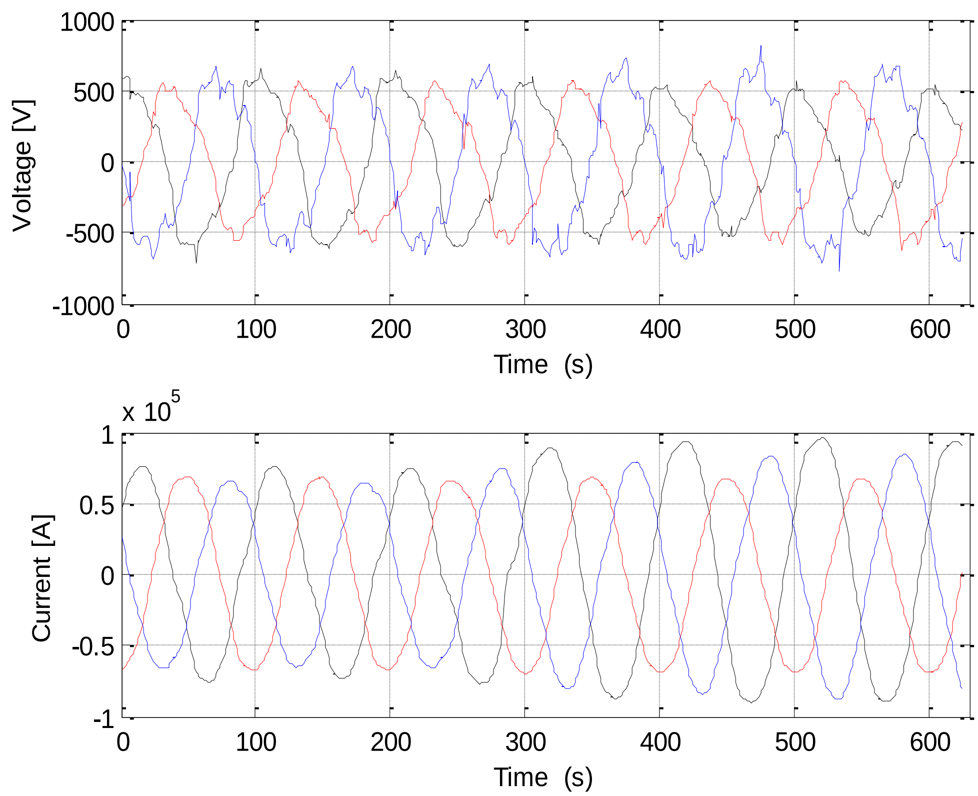


Fig. 2.3.1. The variation of the three phase currents and voltages for the measured data set for the melting stage

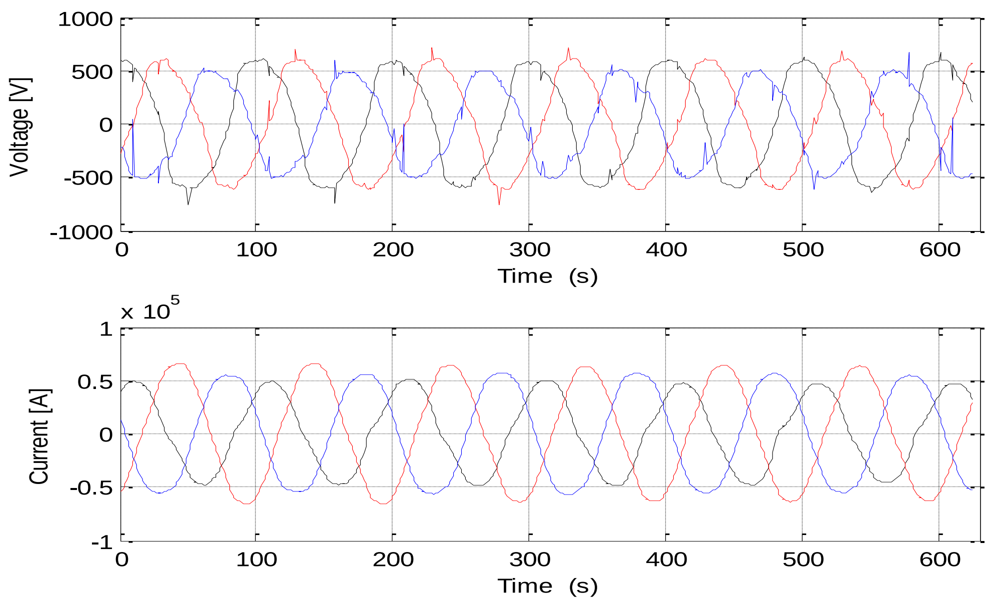


Fig. 2.3.2. The variation of the three phase currents and voltages for the measured data set for the refining stage

One sample consists in 3 currents and tree voltages acquired from the secondary side of the furnace transformer using a data acquisition board ([Pănoiu M 07g]. The training function was trainlm, from the Matlab Neural Networks toolbox that use Levenberg- Marquard method. No other function of Matlab Neural Networks toolbox has better performance. Other parameters of training are: max_fail=6, max epochs=500.

The ANN performance, i.e. training performance, validation performance and testing performance for learning rate between 0.2 and 1 and for hidden neurons between 60 and 120 are shown in table 2.3.1. It can be seen from both, table 2.3.1 and figure 2.3.3.a, that from point of view of training, the network performance increases with the number of hidden neurons. But, from table 2.3.1 and figures 2.3.3.b and 2.3.3.c, it is found that the validation and testing performance increase to approximately 100 hidden neurons then begin to decrease.

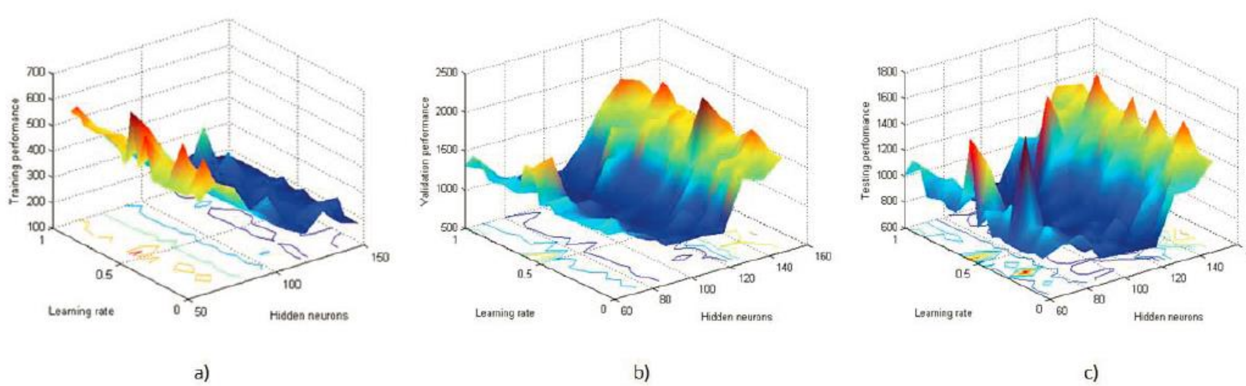


Fig. 2.3.3. a) Variation of ANN trainning performance for MLP-Model; b) Variation of ANN testing performance for MLP-Model; c) Variation of ANN validation performance for MLP-Model

This means that the network loses its ability to generalize over a too large number of hidden neurons, occurring overtraining phenomenon. Regarding the learning rate, is found that both for training, testing and validate the optimal learning rate are between 0.8 and 1.

Based on these observations was chosen network architecture with 100 hidden neurons and learning rate 0.8. For these values, simulation results in figures 2.3.4, 2.3.5 and 2.3.6 were presented. The results have presented for a single phase in order to obtain a clearer image. Figure 2.3.4 shows variation of measured and simulated voltage and in figure 2.3.5 voltage – current characteristics both for measured respectively simulated values are shown. In figure 2.3.6 and 2.3.7 all three phases voltages and currents both for measured values and for simulated values are shown. By analysing these two figures it can be concluded that, the current prediction is better then voltage prediction.

Table 2.3.1. The ANN performance

Hidden neurons	ANN performance	Learning rate				
		0.2	0.4	0.6	0.8	1
60	Training	4.339	4.254	4.348	4.997	5.275
	Validation	12.621	12.291	16.793	12.678	12.962
	Testing	8.611	8.516	10.880	9.314	10.064
80	Training	4.067	3.998	3.909	3.866	3.843
	Validation	10.535	10.369	10.122	10.078	10.095
	Testing	8.890	9.225	8.494	8.394	8.305
100	Training	2.796	2.663	2.597	2.536	2.653
	Validation	8.967	8.414	8.411	8.216	9.107
	Testing	7.611	7.193	7.202	7.170	7.802
120	Training	1.887	1.876	1.829	2.026	1.984
	Validation	8.880	9.151	9.459	11.610	11.740
	Testing	7.307	7.401	7.394	9.717	10.389
140	Training	2.327	1.900	1.989	1.873	1.849
	Validation	16.070	15.270	16.459	15.616	18.568
	Testing	12.809	11.852	12.062	11.599	13.511

For a better comparison of results obtained by modeling with artificial neural networks, the main electrical parameters were determined: apparent power, active power, reactive power, harmonic power. In the table 2.3.2 the powers for measured data set and for simulated data set are presented.

In figures 2.3.4 – 2.3.6, comparisons with measured data from melting phase are shown. The same comparisons were made for the refining stage. These comparisons are shown in figures 2.3.7 and 2.3.8.

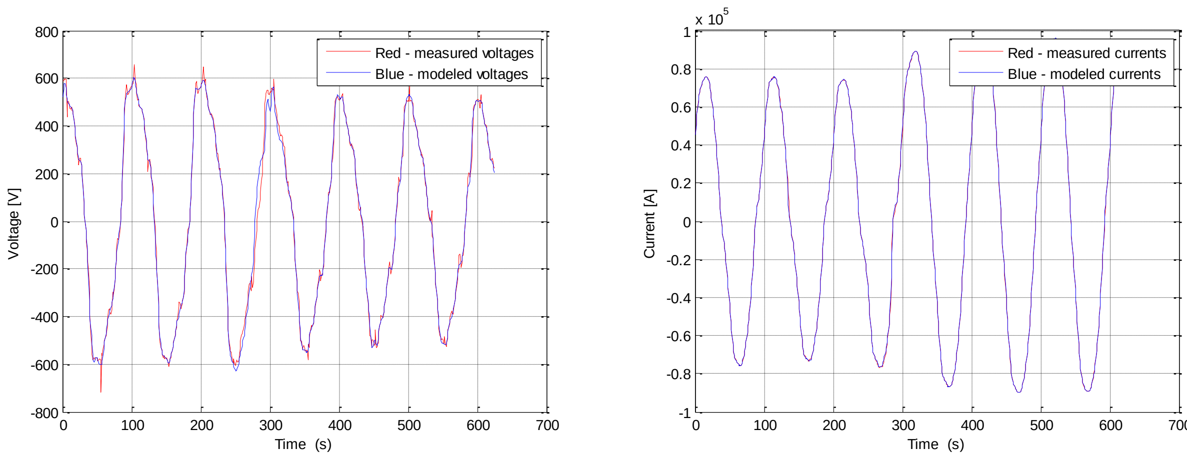


Fig. 2.3.4. Variation of the measured and simulated voltage and current current for phase 1 in refining stage

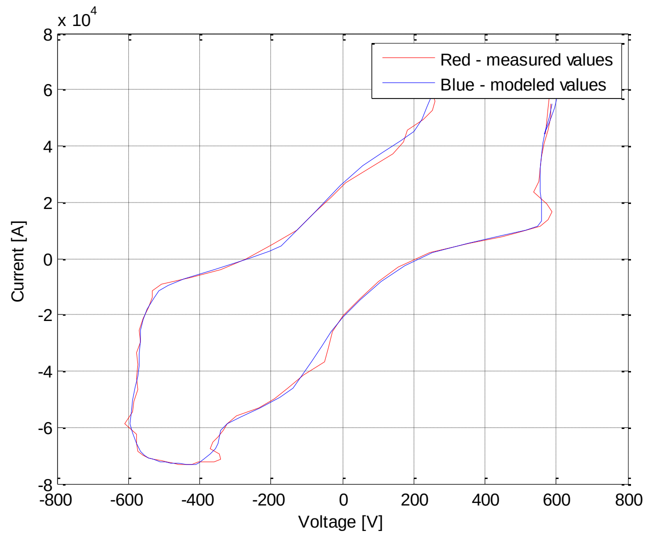


Fig. 2.3.5. The voltage – current characteristics for the melting stage (measured and simulated)

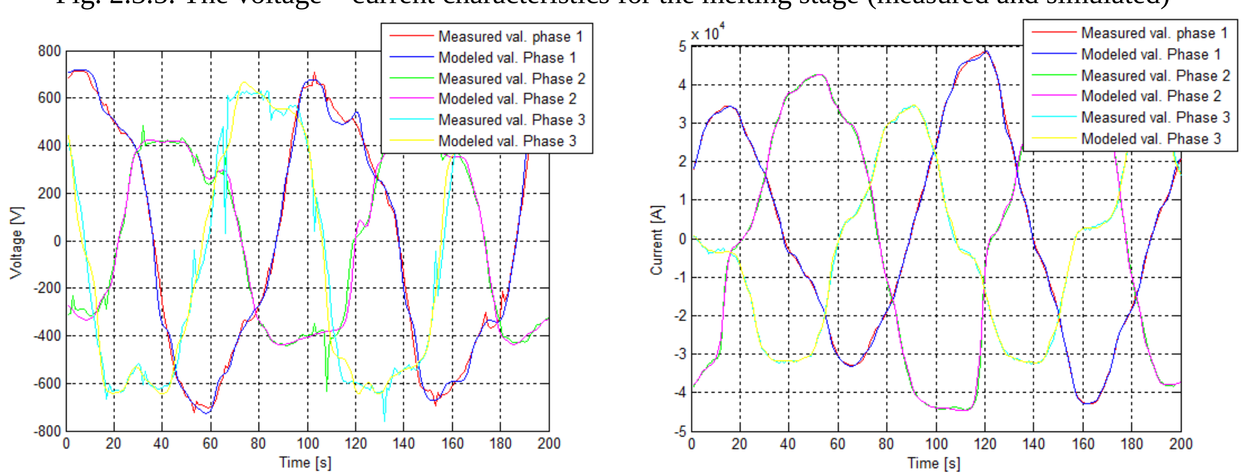


Fig. 2.3.6. Variation of the three phase voltages and currents, measured and simulated

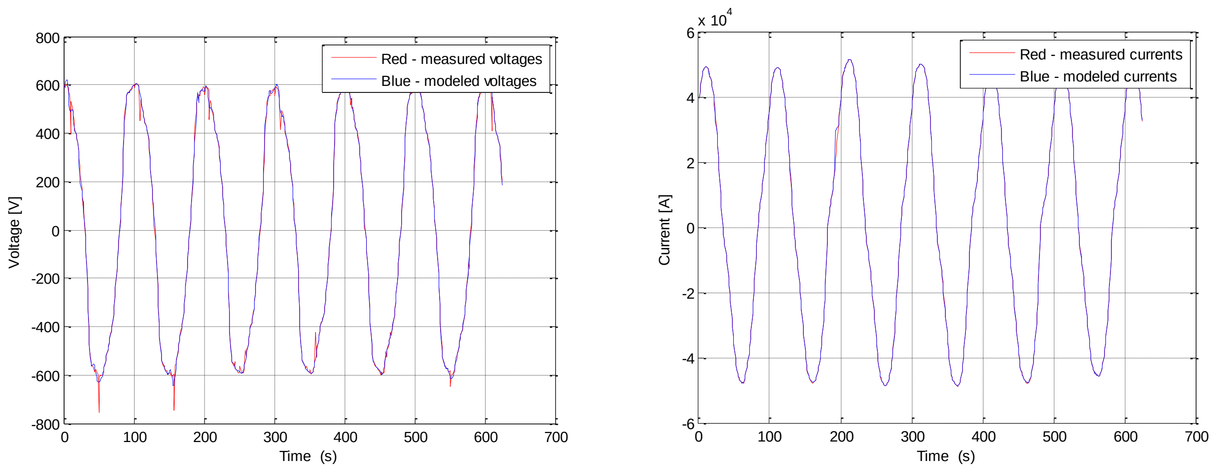


Fig. 2.3.7. Variation of the measured and simulated voltage and current current for phase 1 (from figure 2.3.2, refining stage)

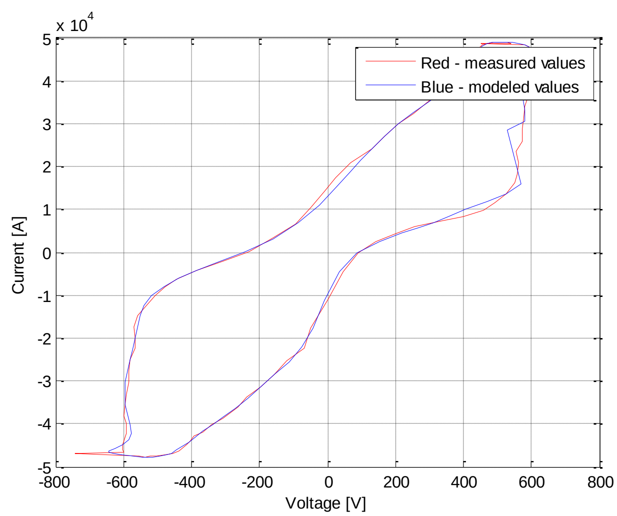


Fig. 2.3.8. The voltage – current characteristics for the refining stage (measured and simulated)

The ANN models were implemented in Matlab 2012 environment. The obtained training and testing results are used to form an ANN model that can estimate the voltage – current characteristic for a variety of meltdown stages. The reliability of the predicted values depends not only on the ANN architecture but also on the input data. The training dataset was used to train the network and testing dataset to check the generalization capability of the network. It was obtained a good generalization capability of the ANN.

It was made both qualitative and quantitative comparisons for the electrical parameters between the simulation results and the performed measurement. By observing the results, it is seen that the current waveforms are completely matched by adopting the advanced models (based on neural networks) due to the direct usage of currents to be the inputs of the models. On the other hand, the classic models cannot very accurately match actual measured EAF current and voltage [Panoiu M 08b], [Panoiu M 13a] and [Ghiormez 13b].

Table 2.3.2. The powers for measured data set and for simulated data set

The electrical power		Measured valued	Simulated values
Apparent power [MVA]	Phase 1	32.188387	32.09877
	Phase 2	26.387481	26.32823
	Phase 3	28.132503	27.94423
Active power [MW]	Phase 1	29.062723	29.05267
	Phase 2	24.523664	24.53982
	Phase 3	23.784713	23.73443
Reactive power [MVAr]	Phase 1	9.952685	9.904773
	Phase 2	8.160376	8.174386
	Phase 3	10.142464	10.26053
Harmonic power [MVAd]	Phase 1	9.612202	9.390028
	Phase 2	5.319520	4.914487
	Phase 3	11.084025	10.59616

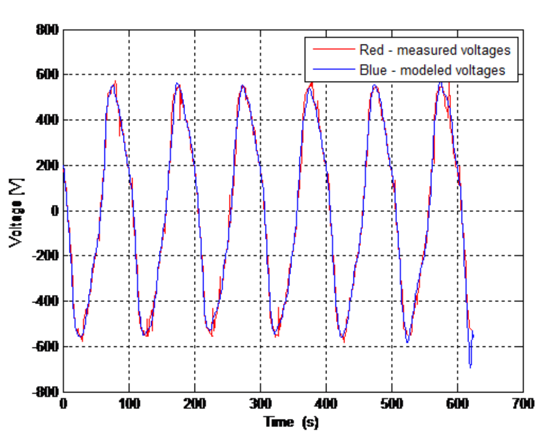
2.3.1.2. Model based on radial bases functions ANN

The radial-basis function artificial neural network (RBF-ANN) is an alternative to the multi-layer perceptron and has paid attention in many applications in recent years due to its simpler structure [Chang 08], [Sadeghian 99b].

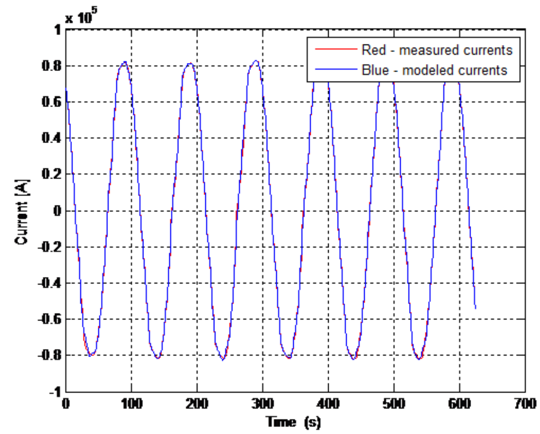
RBF-ANN is a feedforward neural network with a much simpler structure than MLP-ANN. A typical structure of RBF-ANN includes the input layer, the hidden layer and the output layer, [Sadeghian 99b]. The input-output connection consists of two transformations: a nonlinear transformation from the input layer to the hidden layer and linear transformation between hidden and output layers. The RBF networks learn supervised with increasing rates, being designed as functional approximation methods ("curve fitting").

RBF-ANN generally is used for the approximation of curves in multidimensional space. Learning is equivalent with finding a surface in a multidimensional space to match (fit) as described by the input data.

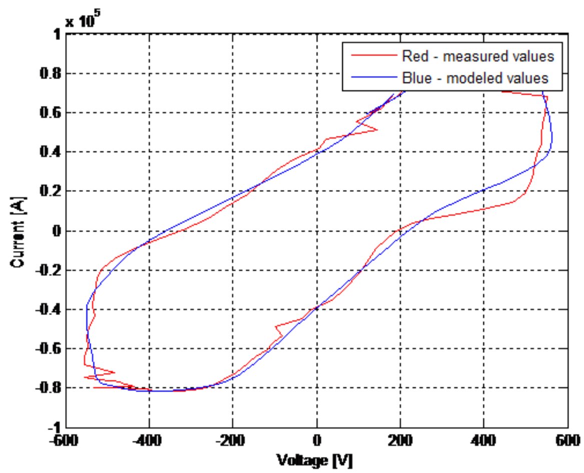
Compared with the multi-layer perceptron networks (RNA MLP), RBF ANN may require more neurons, but their trainning requires less time. This is because the output neurons of the hidden layer MLP are significant for large regions of the input space, while the radial functions based on neurons respond only to relatively small regions of the input space. RNA RBF responds better when more vectors are available.



a)



b)



c)

Fig. 2.3.9. Comparisons between measured and simulated items for refining stage
a) Variation of measured and simulated voltages b) Variation of measured and simulated currents
c) The voltage – current characteristics (measured and simulated)

The most common radial basis function used in RBF-ANN is given by

$$\phi_k(x) = e^{-\frac{(x-wc_k)^T(x-wc_k)}{2\sigma_k^2}} \qquad (38)$$

Where x is the input vector data, w_{ck} is central vector for a hidden neuron, *k* is the normalization factor.

By using the measured values of the current and voltage at the RBF-ANN input as input vectors, respectively estimated values, an approximation for the current voltage characteristic *V-I* can be obtained. The training parameters used by *newrb* function from the Matlab Neural Network Toolbox were *eg=0.1* (Mean squared error goal) and *sp = 2* (Spread of radial basis functions).

Comparison between measured and simulated items for this model, in refining stage, is presented in figure 2.3.9.

2.3.2. Adaptive neuro-fuzzy system for current prediction in electric arc furnaces

In this section current prediction is studied taking into account ANFIS model parameters. In order to achieve ANFIS model measured data were used in both initial melting and refining stage. Because in the initial melting stage the currents are more distorted, in [Pănoiu M. 14a] this case was only presented. Also, *n* samples were used: the first *n/2*, training data set, were used for training the ANFIS, while the remaining *n/2*, checking data set, were used for validating the identified model.

It was demonstrate that ANFIS can be employed to predict future values of a chaotic time series [Jang 93]. In order to make a prediction in time of the current or voltage of the electric arc the measured values for the current and voltage up to a moment *t* were used to predict a value at a moment *t+p*. This can be done by creating a mapping from *d* sample data points, sampled every units in time with sample time *s*, $[x(t-(d-1)\cdot s),\cdots,x(t-s),x(t)]$ in order to predict a value of the current at moment *t+p*, i.e. $x(t+p)$. If it is reffered at current and voltage, *x* vector is given by relation (39)

$$x=[i(t-(d-1)\cdot s),v(t-(d-1)\cdot s)\cdots,i(t-s),v(t-s),i(t),v(t)] \tag{39}$$

For example, if it is desired a prediction for the moment *p = 4* and 3 samples are used, i.e. *d = 3* and sample time is *s = 4*, the training data vector should be formed as:

$$trn=[x(t-8),x(t-4),x(t)] \tag{40}$$

and corresponds to the prediction for the output value $y=x(t+4)$. These elements are illustrated in figure 2.3.10. For each moment *t*, in range 4 ÷ *n* training input/output data are represented by a structure in which the first component is the vector *trn* and the next component is the output *y*. If there are *n* measured data, it can be used *n/2* for the training and *n/2* for the checking. For the testing a full sample of measured data was used. Figure 2.3.10 presents measured data used in order to test the performance of the ANFIS system. These data were measured in the melting phase of the charging material after approximately 12 minutes from the beginning of the elaboration process of charge.

In table 2.3.3 it can be noticed that the number of fuzzy sets for the input data was modified in range 2 ÷ 4. Also, the past number of samples used for the prediction was modified. For the training ANFIS system uses Sugeno inference mechanism and also a training method based on a hybrid algorithm. Grid partition is used for FIS generation. Performance of the ANFIS system was determined taking into account the error obtained at training, checking and testing using measured data, as was previously mentioned.

In the presented case in this research 600 samples were used, respectively 300 measured samples for training, the rest of 300 measured samples for checking and the whole 600 measured samples for testing of the ANFIS system. These measured data were acquired with an acquisition frequency of 5 kHz, as presented in [Pănoiu M 09a], [Pănoiu M 07a], [Pănoiu M 07g].

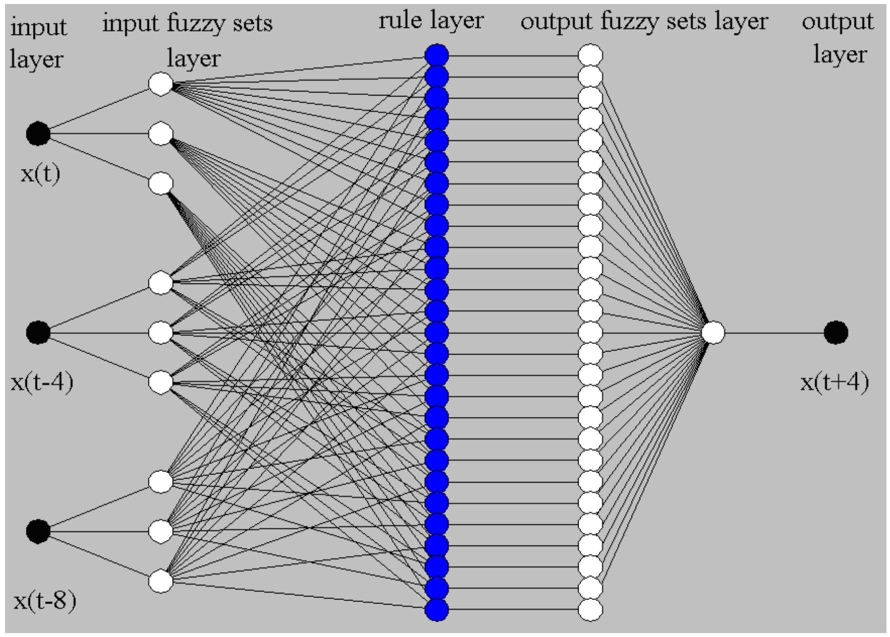


Fig. 2.3.10. The ANFIS structure for sample time *s=4*, past samples *d=3* and step ahead *p=4*

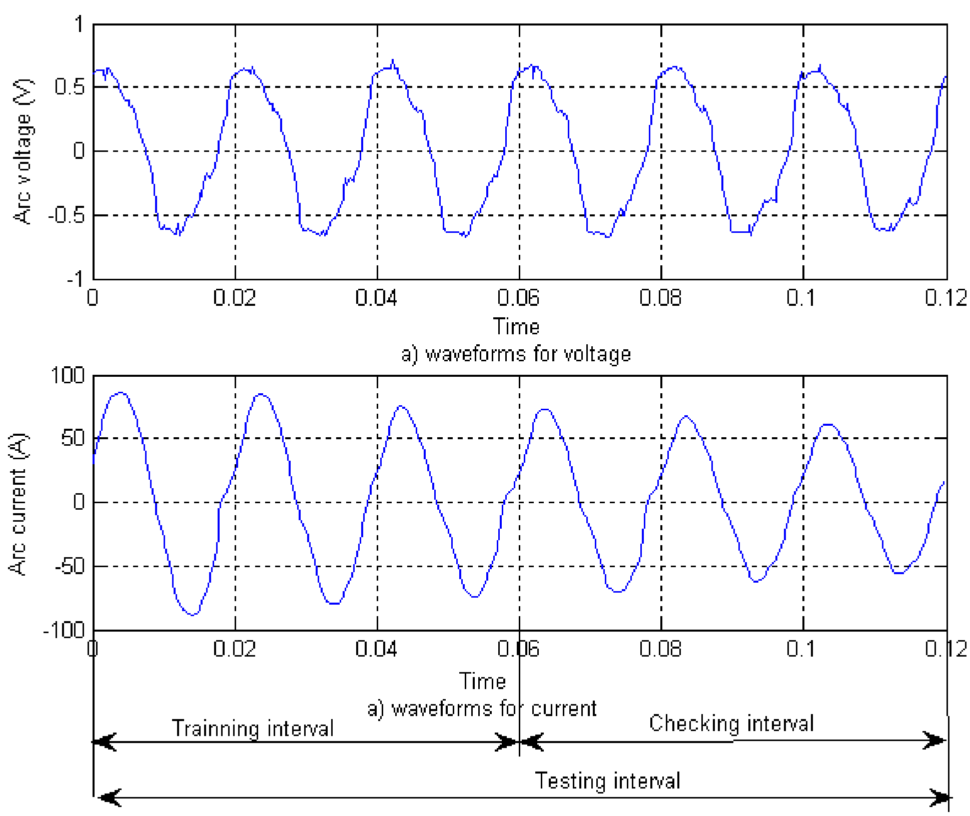


Fig. 2.3.11. The waveforms for training, checking and testing data.

If it is trying a prediction for *p=5* or *p=6* steps ahead, with the same parameters above mentioned, the error increases around value 4.43, at 2 fuzzy sets for each input of the ANFIS system. In this case, if there are used many fuzzy sets for the input values, for the training a better error will obtain, but at checking and testing will be observed the overtraining phenomenon.

From table 2.3.3 it can be noticed that in the case of using a smaller number of data, n=300 instead of 600, the ANFIS system do not offer better performance. This is happened because there are too less data and from these data the analyzed system characteristics cannot be extracted correctly. Therefore, it can be observed, for example, that for a prediction p=6 steps ahead, the obtained error for the training data is very good, 1.79, but at testing and checking the obtained error increases very much reaching up to approximately 14 at checking and approximately 9 at testing.

Also can be observed that in some cases (*s=2, d=3, p=2; s=2, d=4, d=2; s=3, d=4, d=3; s=2, d=4, p=4* and *s=6, d=4, p=6*) the errors are not modified with increasing the epoch number.

Analyzing all the presented situations from table 2.3.3 it can be concluded that as from the obtained error and also from the training time point of view, an acceptable case has the next parameters: sample time *s=3*, past samples *d=4*, step ahead *p=3*, when the obtained error at testing is 2.75 at 2 fuzzy sets on the input. It can be noticed that in figure 2.3.12 the variation of the nonlinear surface for the output is depending on two values of the input. In figure 2.3.13 it can be observed the error variation for a training set of 500 epochs.

It can be noticed from table 2.3.3 that the smaller error obtained at the system testing is 2.00, obtained for the sample time *s=2*, past sample number *d=3* and step *p=2*. ANFIS system has used in this case *4* fuzzy sets for each input and the training was performed for 100 epochs. Raising the number of training epochs will not obtain a smaller error, otherwise the error grows. Another small error, 1.65 was obtained for the case in which 4 steps ahead for the prediction were used *p=2*, with the sample time *s=2*. ANFIS system training parameters were: epochs number *e=500* and the number of fuzzy sets for each input 2. The same situation but using less training epochs carries on approximately the same result and testing error is 2.75. For this case, raising the number of epochs has none advantage because even if a smaller error at training was obtained, the training time grows considerably. Also, it is not a good idea to increase the number of fuzzy sets, because it can be noticed that the checking and the testing error is increased for 3, respectively 4 fuzzy sets. In this case the overtraining phenomenon appears.

Figure 2.3.14 shows the variation in time of the measured current, and also the variation of the output of the ANFIS system, i.e. for the predicted value of the current.

If it is desired a prediction for p=6 steps ahead, the error is increasing. So, it can be see that when are chosen sample time s= 6, past samples d=4, step ahead p=6, the obtained error at testing is 4.43 for two fuzzy sets at each input. In figure 2.3.15 the time variation of the output ANFIS system was presented, i.e. for the predicted current and also for measured current for 500 epoch of training.

Table 2.3.4 The obtained errors in training, checking and testing process

No. crt.	Nr. Fuzzy sets	Error for 100 epoch			Error for 500 epoch		
		Train	Check	Test	Train	Check	Test
1. Sample s= 2, past samples d=2, step ahead p=2							
a	2	9.24	9.15	9.19	3.62	3.19	3.41
b	3	3.26	4.94	4.18	2.52	3.49	3.04
c	4	2.83	3.44	3.15	2.43	3.26	2.88
2. Sample s= 1, past samples d=3, step ahead p=1							
a	2	8.19	7.72	7.96	5.34	4.27	4.84
b	3	5.81	5.93	5.87	3.6	3.46	3.53
c	4	5.05	4.85	4.93	4.13	3.70	3.92
3. Sample s= 2, past samples d=3, step ahead p=2							
a	2	3.37	5.08	4.13	2.14	1.69	1.93
b	3	1.63	4.43	3.34	1.63	4.43	3.34
c	4	1.06	2.63	2.00	0.97	3.25	2.39
4. Sample s= 3, past samples d=3, step ahead p=3							
a	2	15.81	13.61	14.78	15.11	13.43	14.31
b	3	12.07	11.32	11.71	9.02	8.54	8.78
c	4	11.74	10.72	11.25	8.85	8.21	8.54
5. Sample s= 2, past samples d=4, step ahead p=2							
a	2	2.50	2.66	2.56	1.51	1.74	1.63
b	3	1.17	6.39	4.57	1.17	6.39	4.57
c	4	0.74	6.75	4.78	0.74	6.75	4.78
6. Sample s= 3, past samples d=4, step ahead p=3							
a	2	2.76	2.74	2.75	2.03	2.13	2.08
b	3	1.20	8.94	6.34	1.20	8.94	6.34
c	4	0.88	7.73	5.47	0.88	7.73	5.47
7. Sample s= 4, past samples d=4, step ahead p=4,							
a	2	2.98	3.38	3.18	2.62	3.67	3.18
b	3	1.25	11.41	8.06	1.23	11.27	7.96
c	4	0.91	11.14	7.85	0.9	11.15	7.85
8. Sample s= 2, past samples d=4, step ahead p=4,							
a	2	3.59	4.89	4.28	3.02	3.75	3.4
b	3	1.64	8.32	5.96	1.64	8.32	5.96
c	4	1.17	10.67	7.55	1.17	10.67	7.55
9. Sample s= 6, past samples d=4, step ahead p=6							
a	2	3.23	5.36	4.43	3.02	5.65	4.53
b	3	1.79	13.39	9.55	1.79	13.39	9.55
c	4	1.13	34.19	24.19	1.13	34.19	24.19

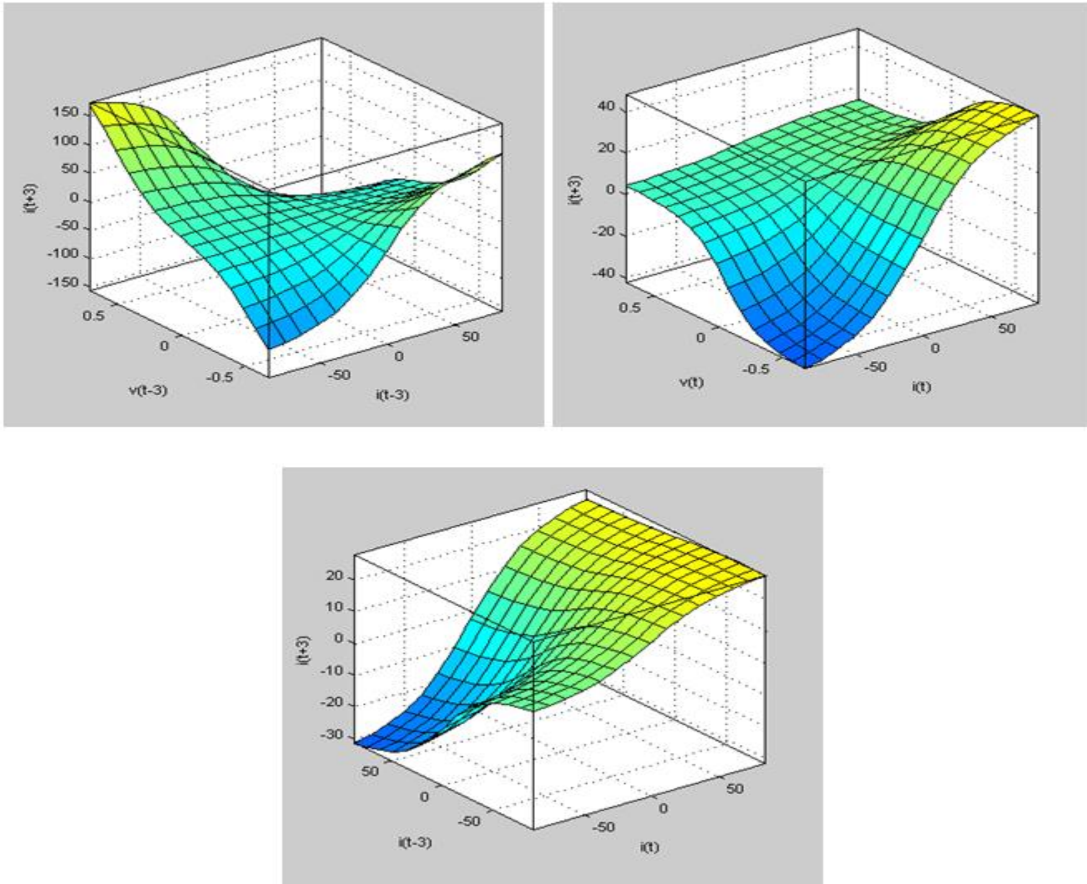


Fig. 2.3.12. Variation of system output on two system inputs for sample time *s= 3*, past samples *d=4*, step ahead *p=3* and 2 fuzzy sets

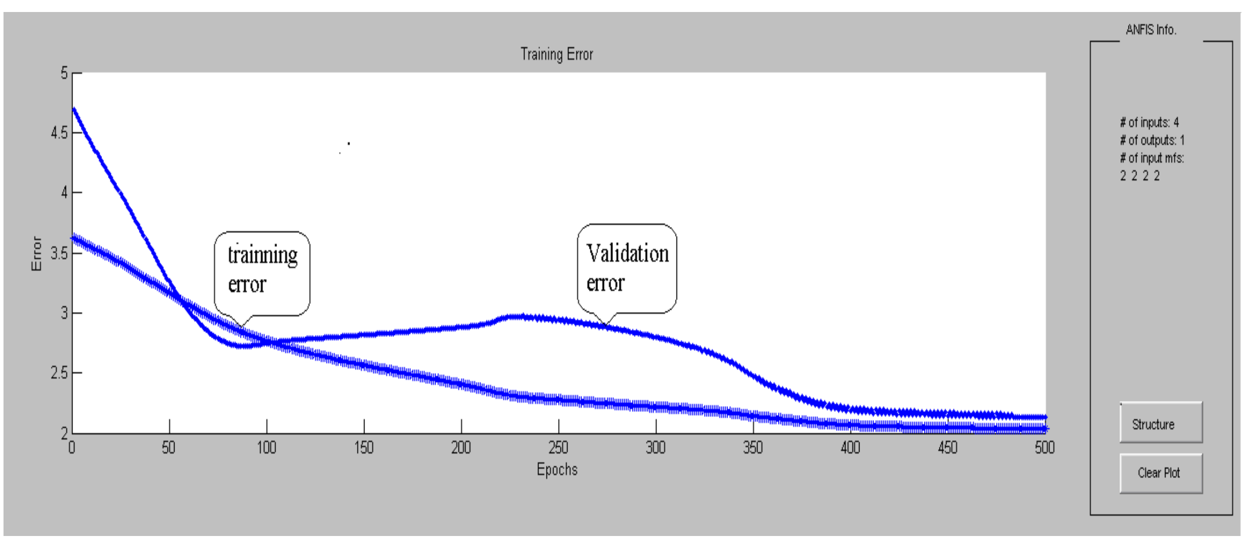


Fig. 2.3.13. Variation of training error and validation error for sample time *s= 3*, past samples *d=4*, step ahead *p=3* and 2 fuzzy sets

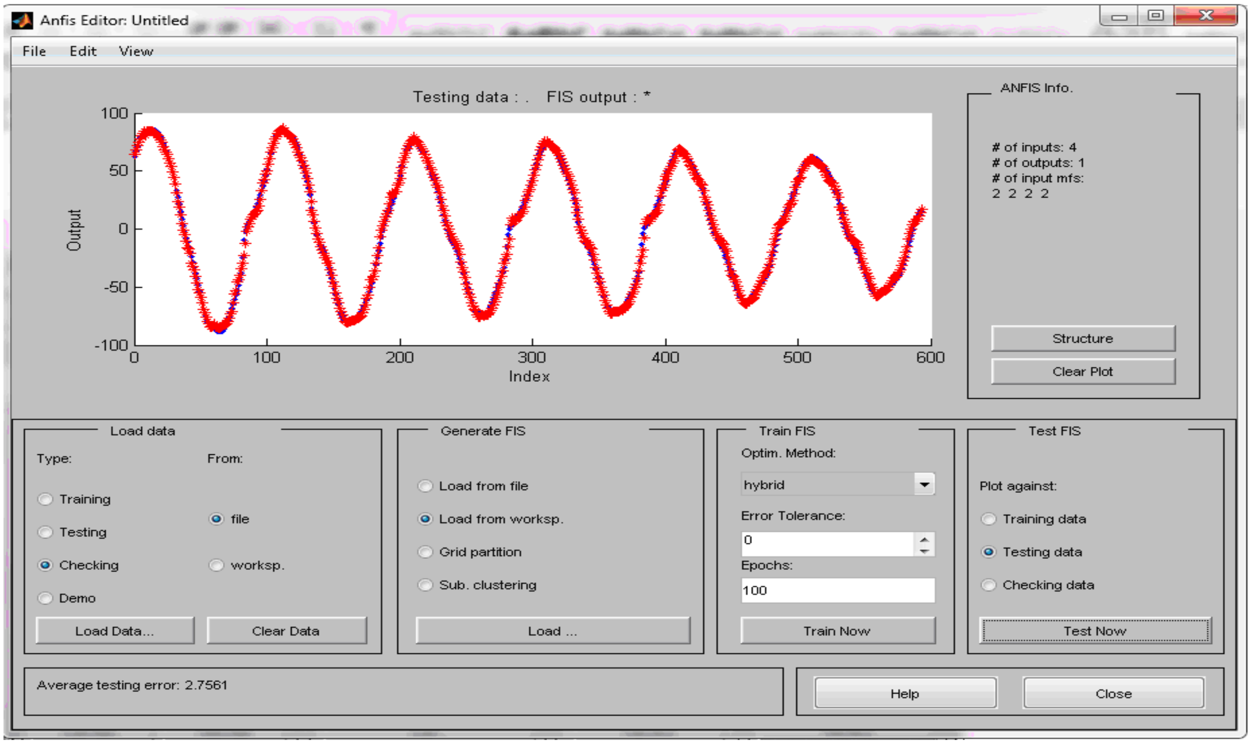


Fig. 2.3.14**.** The variation of the measured data (blue) and the predicted current (red) for sample time *s= 3*, past samples *d=4*, step ahead *p=3* and 2 fuzzy sets

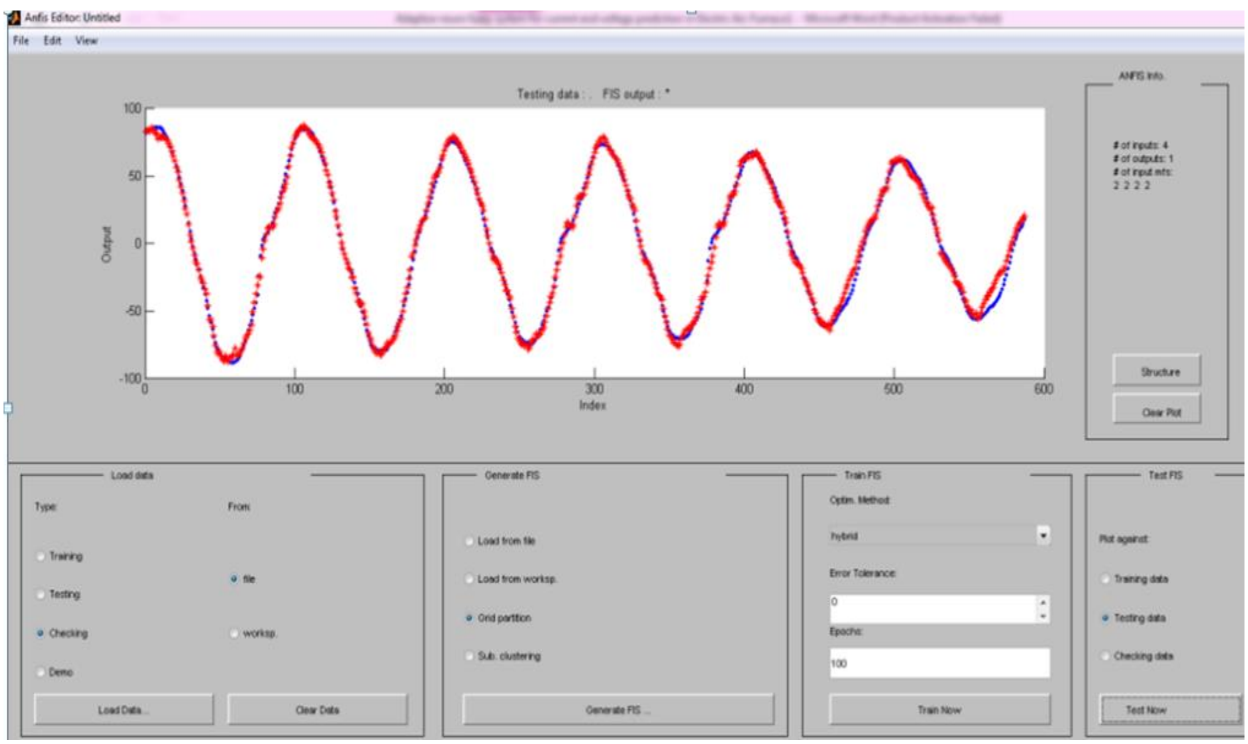


Fig. 2.3.15. The variation of the measured data (blue) and the predicted current (red) for sample time *s= 6*, past samples *d=4*, step ahead *p=6* and 2 fuzzy sets.

From those previously presented we can conclude that a detailed study was performed regarding the possibility of using an intelligent ANFIS system for the prediction of the current of an electric arc furnace. This study can offer important information which are useful in order to build a system that assumes the reactive power compensation and rejection of the harmonic currents in the case of electric arc furnace installation. By using the prediction in real time for the electric current value, such a system used for the rejection-compensation can adapt its parameters in real time to obtain the maximum efficiency. Made study was based on acquired values taken off line in the installation of an electric arc furnace and having capacity of 100 tones and a power of 70 MW. Following the study, conclusions regarding the proper structure of the ANFIS system were taken, number of used data for the training system and the number of steps ahead for which can be performed another correct prediction.

2.3.3. Research based on the fuzzy logic applications

2.3.3.1. The protection of the contact line and the connective devices in electric railway traction system using fuzzy logic

One of the fuzzy logic projects in which the candidate has participated consists of the practical implementation of a fuzzy controller for the protection of the contact line and the connective devices in electric railway traction system.

The candidate was member of the research team that worked to a research project with SC Softronic SRL Craiova, contract entitled "Fuzzy expert system for the protection of the contact line and the connective devices in electric railway traction system”. A complex protective relay for the contact line was designed and implemented. The protection of any electrical equipment must ensure the automatically disconnecting in the event of a fault or an abnormal system operation.

The effective contribution of the candidate to the project consisted in the actual programming of the Fuzzy controller on a DSP TMS320F2812 signal processor. For this reason, this part of the research will be presented.

The contact line in electric railway traction has different mechanical and electrical characteristics, dissimilar to usual power systems. There are some abnormal operating modes that are specific to this situation: short-circuit in the contact line (CL), sub-sectioning (SSP) or in traction substations (TS). These abnormal regimes are produced by the pantograph of the electric locomotive. In the case of electrified railway lines through the mono-phase system, at 50 Hz frequency, the distance between two TS is 50 ÷ 60 km, depending on the line profile.

For the simple lines, the high characteristic impedance of $0.47\ \Omega / km$, leads to a minimal short circuit current, at the end of the line, less than the maximum operating currents.

Currently, the long-distance protection is ensured by *di/dt* relays or impedance relays.

These methods have a number of disadvantages [Rusu-Anghel 11a], [Rusu-Anghel 11b] and should be replaced in the future with more modern and efficient protective methods [Rusu-Anghel 11a]. Comparisons between different protection relays as well as their characteristics and disadvantages are presented in [Rusu-Anghel 11a] [Farzad 10]:

- processing techniques for conventional signals are not suitable for high speed protection because they have a long time response;
- errors in computing the line impedance;
- the wrong classification of faults due to the presence of fault resistance, this being the most dangerous.

Due to these disadvantages and of other ones detailed in [Rusu-Anghel 11b], other protection techniques must be used. A more modern approach is to use fuzzy logic as described in [Vaslan 09].

Artificial Intelligence / Fuzzy expert systems exceed the limitations outlined above because they have the advantage of a quick response and of increased accuracy compared to conventional techniques. The ability of fuzzy protection system is only limited by the fact that a prior knowledge is required.

Structure of the protection device

In order to protect the contact line against the abnormal regimes, a complex device was conceived. This device replaces the maximum current relay, the minimum voltage relay and the impedance relay, as well. The principle scheme is presented in figure 2.3.16.

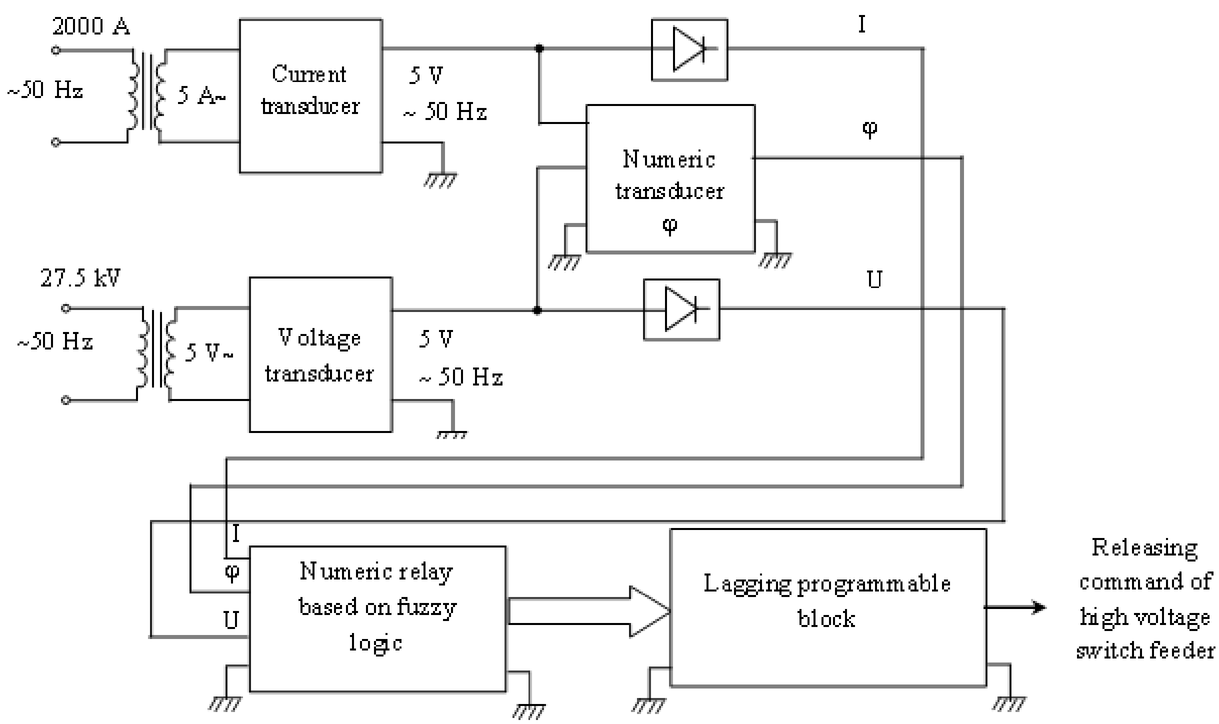


Fig. 2.3.16. Structure of the protection device

The voltage and currents signals are acquired from the secondary windings of the measuring transformers from power supply substation. They are transformed into 5V alternative signals domain using appropriate transducers that realize the galvanic isolation, as well. The imposed essential conditions are linearity and keeping the phase correspondence between the input and outputs signals, in order not to introduce errors into the measuring process of the voltage - current phase displacement.

In order to determine the phase displacement, a numeric transducer of high accuracy was conceived. The lagging command in case of short-circuit is realized during the current first cycle.

The processing of three signals (*U*, *I*, *φ*) is numerically realised by a complex relay based on fuzzy logic. The rules assembly is accomplished by a human expert group and can be modified anytime, ensuring in this way the relay adaptation to any real functioning condition of contact line. The relay structure is based on a dedicated microcontroller with necessary circuits: memories, A/N and N/A converters.

After defuzzification process, the relay output commands a lagging programmable circuit, so, the high voltage switch releasing has to be made at the times imposed by rule base. The constructive details of the mentioned blocks are presented in figure 2.3.17. This device must generate the releasing command of the high voltage switch with a variable lagging in function of the fuzzy analyzing conclusions generated by the microcontroller. (“0” – blocked, “1” - instantaneous).

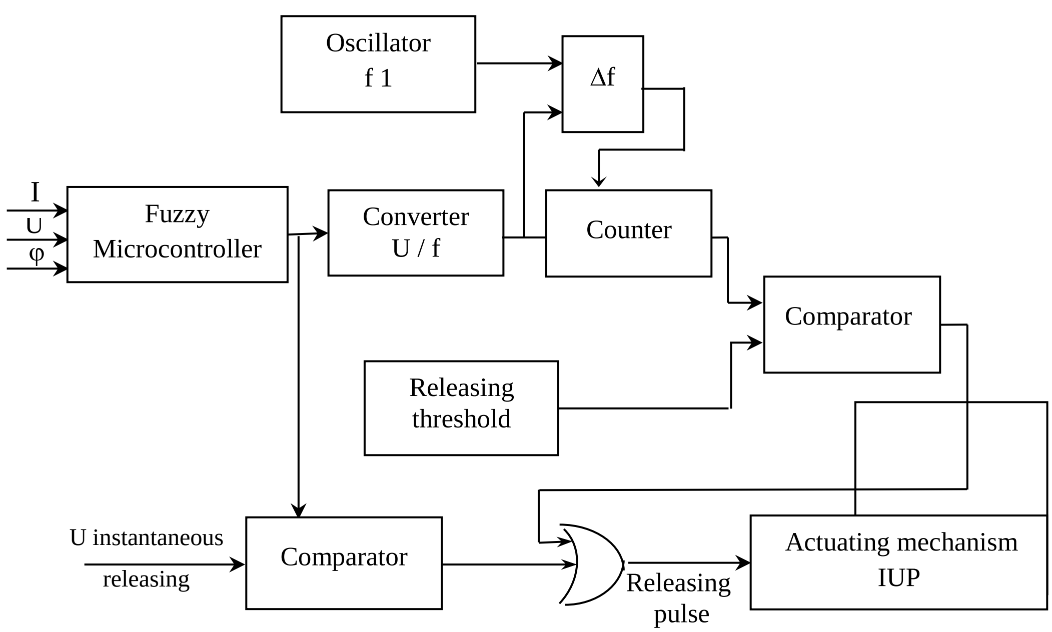


Fig. 2.3.17. The lagging programmable circuit

Signal generated by the fuzzy controller varies between 0V (“0”) and 5V (“1”). “0” corresponds to situation when the switch releasing must not be produced and “1” when the releasing must be instantaneous. The voltage signal is linearly converted into a frequency signal. The characteristic is presented in figure 2.3.18.

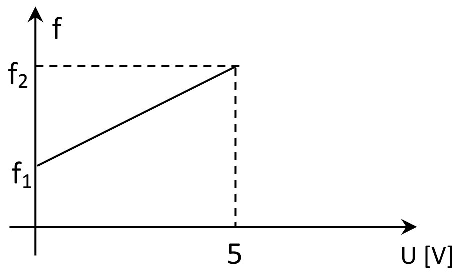


Fig. 2.3.18. The characteristic of the lagging programmable circuit

The circuit Δf provides a square signal with the frequency varying between zero and f_2-f_1. The comparator compares the counter content with a fixed number called releasing threshold and when the equalization is produced, the releasing pulse is generated. With the increasing of the fuzzy controller voltage, this number is reached rapidly and the releasing will be produced rapidly as well. In order to ensure the instantaneous releasing with high accuracy, a comparing circuit was designed. Presented device compares the controller voltage with a threshold voltage in order the releasing pulse to be generated in this way, as well.

The fuzzy protection block. The base rules for fuzzy relay

As was mentioned, for complex protection of the contact line supplied, 27.5 kV and 50 Hz, a fuzzy relay was conceived considering the practical case of an electric railway traction substation. This relay accomplishes the maximum current protection, the overload protection, distance protection and minimum voltage protection.

In figure 2.3.19 the fuzzy relay block scheme is presented.

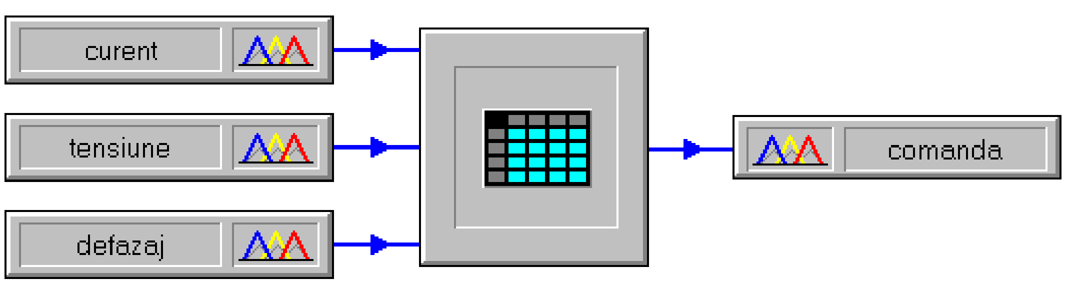


Fig. 2.3.19. Fuzzy relay block scheme

Due to the percent scale of representation of the transfer functions corresponding to the processed elements (0 ÷100%), the discussion domain norming was necessary.

a) Information concerning input elements

Following usually regimes were considered:

a1) for ***current***:

Linguistic values for the linguistic variable "current"	Variation domain, crisp values [A]	Variation domain, fuzzy values [A]	Discussion domain [%]
normal	50 ÷ 600	50 ÷ 616	0 ÷ 30.8
overload	600 ÷ 800	512 ÷ 820	25.6 ÷ 41
shortcircuit	800 ÷ 2000	718 ÷ 2000	35.9 ÷ 100

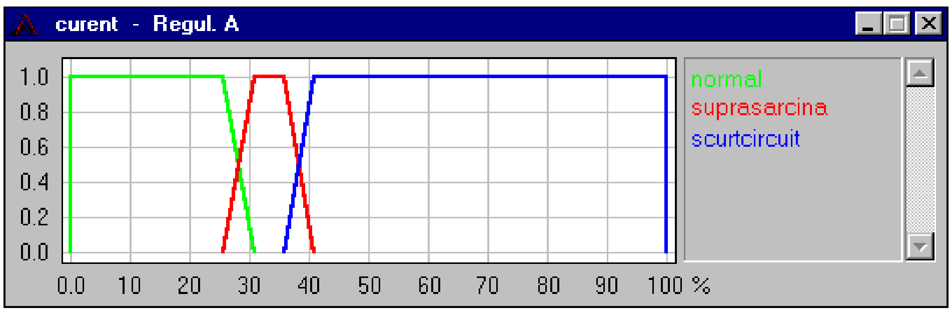


Fig. 2.3.20 The appartenance functions for the input element "current"

a2) for ***voltage***:

Linguistic values for the linguistic variable "voltage"	Variation domain crisp values [kV]	Variation domain fuzzy values [kV]	Discussion domain [%]
shortcircuit	16 ÷ 20	16 ÷ 27.96	0 ÷ 43.5
overload	20 ÷ 25	23.17 ÷ 39.92	26.1 ÷ 87
normal	25 ÷ 27.5	35.14 ÷ 27.5	69.6 ÷ 100

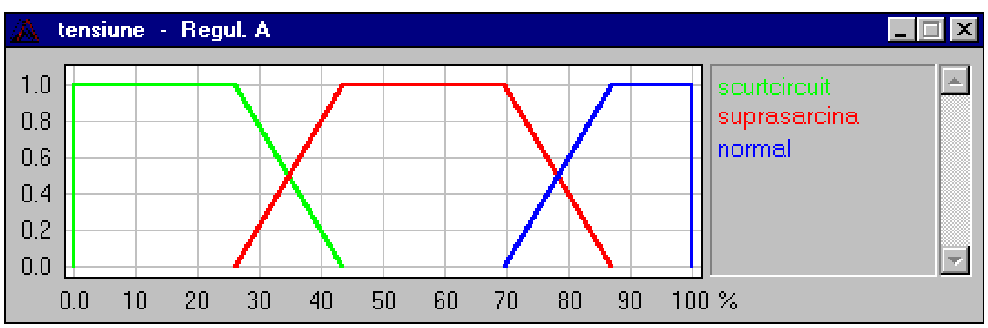


Fig. 2.3.21. The appartenance functions for the input element "voltage"

a3) for ***phase shift***:

Linguistic values for the linguistic variable ”phase shift”	Variation domain crisp values [°]	Variation domain fuzzy values [°]	Discussion domain [%]
normal	0 ÷ 30	0 ÷ 35.04	0 ÷ 43.8
overload	30 ÷ 60	25.04 ÷ 65.04	31.3 ÷ 81.3
shortcircuit	60 ÷ 80	55.04 ÷ 80	68.8 ÷ 100

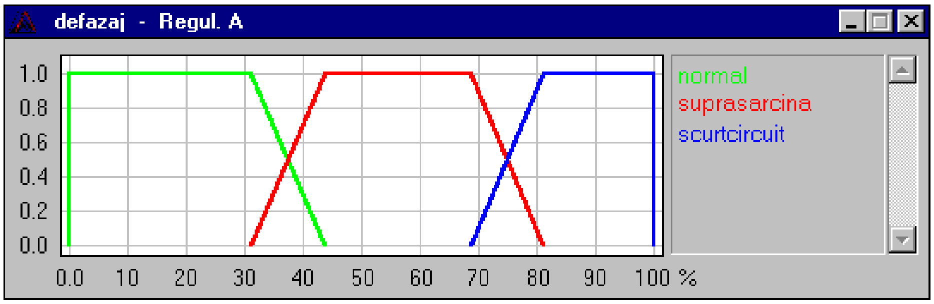


Fig. 2.3.22. The appartenance functions for the input element “phase shift”

b) Information concerning output elements (command)

Linguistic values for the linguistic variable ”command”	Variation domain [V]	Discussion domain [%]
blocked	0	0
highdelay	1.66	33.3
lowdelay	3.33	66.6
instant	5	100

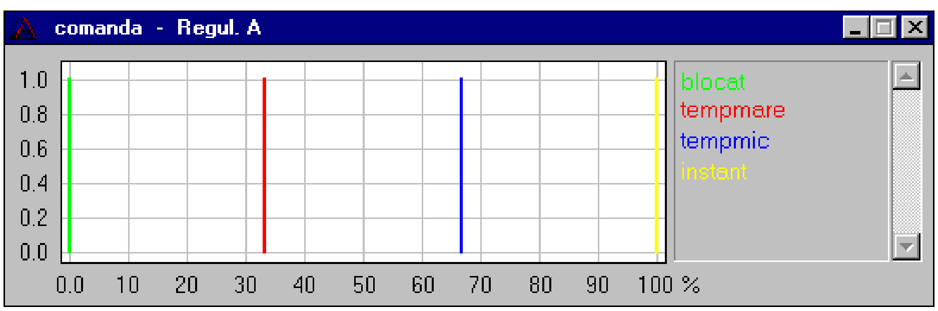


Fig. 2.3.23. The appartenance functions for the output element “command”

c) Inference rules

Rules were established by practically considerations, by consultation the experts in electrical traction domain and in protection installation of the electrical systems domain.

In figure 2.3.24 the inference table is presented. This table connects the fuzzy input variable with the output variable using max-min inference method. For defuzzyfication the singleton weight centres method was chosen due to the short processing time, a very important condition for real-time functioning of the fuzzy relay. So, singleton appartenance functions were chosen.

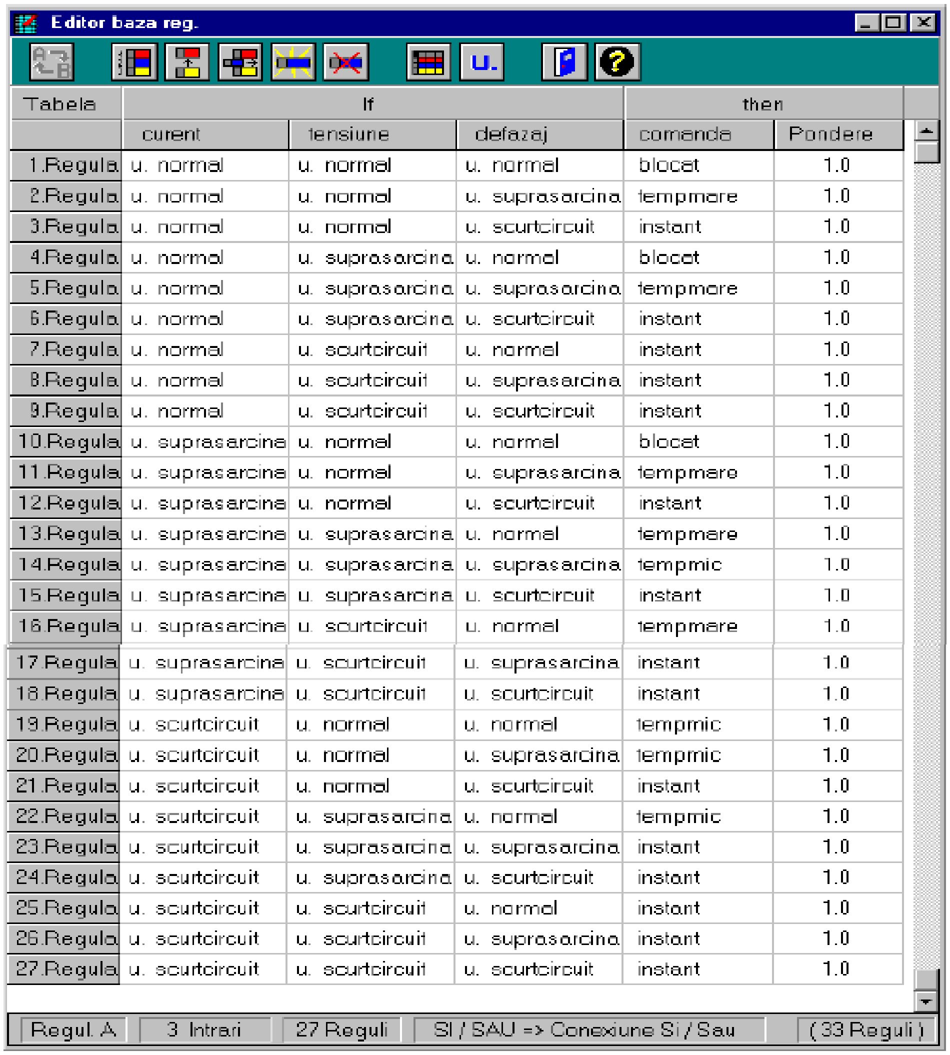

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Tabela	If			then	
	curent	tensiune	defazaj	comanda	Pondere
1.Regula	u. normal	u. normal	u. normal	blocat	1.0
2.Regula	u. normal	u. normal	u. suprasarcina	tempmare	1.0
3.Regula	u. normal	u. normal	u. scurtcircuit	instant	1.0
4.Regula	u. normal	u. suprasarcina	u. normal	blocat	1.0
5.Regula	u. normal	u. suprasarcina	u. suprasarcina	tempmare	1.0
6.Regula	u. normal	u. suprasarcina	u. scurtcircuit	instant	1.0
7.Regula	u. normal	u. scurtcircuit	u. normal	instant	1.0
8.Regula	u. normal	u. scurtcircuit	u. suprasarcina	instant	1.0
9.Regula	u. normal	u. scurtcircuit	u. scurtcircuit	instant	1.0
10.Regula	u. suprasarcina	u. normal	u. normal	blocat	1.0
11.Regula	u. suprasarcina	u. normal	u. suprasarcina	tempmare	1.0
12.Regula	u. suprasarcina	u. normal	u. scurtcircuit	instant	1.0
13.Regula	u. suprasarcina	u. suprasarcina	u. normal	tempmare	1.0
14.Regula	u. suprasarcina	u. suprasarcina	u. suprasarcina	tempmic	1.0
15.Regula	u. suprasarcina	u. suprasarcina	u. scurtcircuit	instant	1.0
16.Regula	u. suprasarcina	u. scurtcircuit	u. normal	tempmare	1.0
17.Regula	u. suprasarcina	u. scurtcircuit	u. suprasarcina	instant	1.0
18.Regula	u. suprasarcina	u. scurtcircuit	u. scurtcircuit	instant	1.0
19.Regula	u. scurtcircuit	u. normal	u. normal	tempmic	1.0
20.Regula	u. scurtcircuit	u. normal	u. suprasarcina	tempmic	1.0
21.Regula	u. scurtcircuit	u. normal	u. scurtcircuit	instant	1.0
22.Regula	u. scurtcircuit	u. suprasarcina	u. normal	tempmic	1.0
23.Regula	u. scurtcircuit	u. suprasarcina	u. suprasarcina	instant	1.0
24.Regula	u. scurtcircuit	u. suprasarcina	u. scurtcircuit	instant	1.0
25.Regula	u. scurtcircuit	u. scurtcircuit	u. normal	instant	1.0
26.Regula	u. scurtcircuit	u. scurtcircuit	u. suprasarcina	instant	1.0
27.Regula	u. scurtcircuit	u. scurtcircuit	u. scurtcircuit	instant	1.0

Regul. A | 3 Intrari | 27 Reguli | SI / SAU => Conexiune Si / Sau | (33 Reguli)

Fig. 2.3.24. The inference table for “command”

The accomplished researches referring to the ‘human expert’ behaviour evidenced that to this one a strongly nonlinear behaviour is specified, close to effects as anticipation, integration, prediction or even adapting to the functioning conditions. By accentuating the linguistic characterization of the process development, the parameters for modifying the regulator properties were accomplished.

In consequence, the designed fuzzy algorithm leads to a nonlinear regulator, with characteristics presented in the following paragraph. In order to represent the spatial regulation characteristics and due to three input variables, u, i, φ, two variables were chosen in the first place, the third being considered as parameter. Therefore, in figures 2.3.25, the surfaces characteristics were represented taking the “current” and “voltage” as variables and the “phase shift” as parameter, i.e. three cases: shortcircuit, normal and overload.

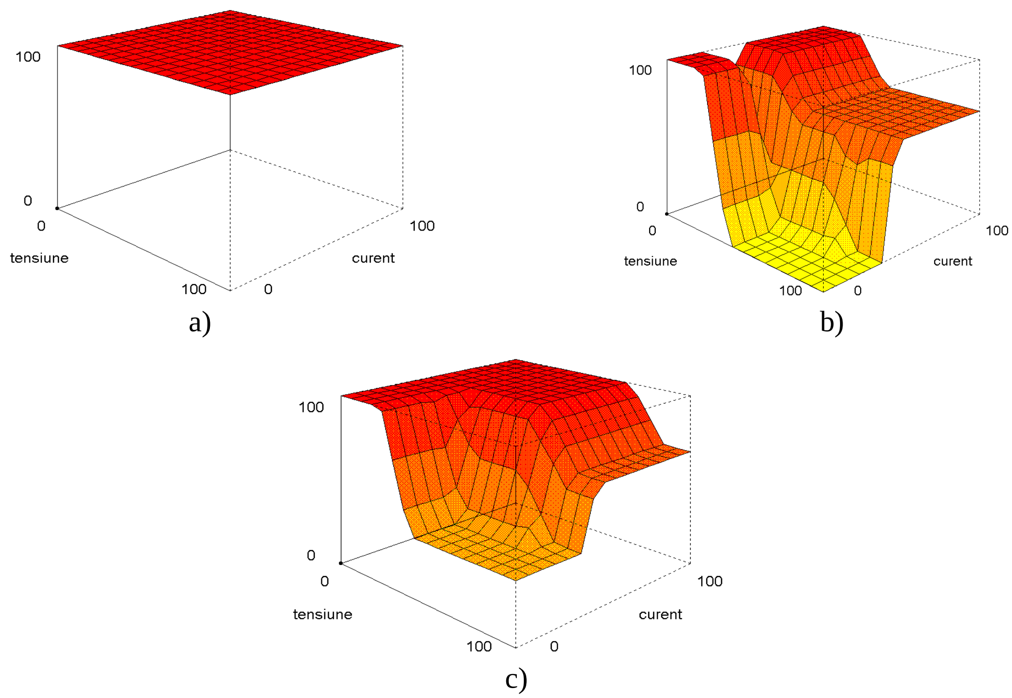


Fig. 2.3.25. “Voltage” – “current” command surfaces for different constant values of “phase shift” variable

In figures 2.3.26 the surface characteristics are represented for “phase shift” and “current” variables, considering “voltage” as parameter, i.e. three values: shortcircuit, normal and overload.

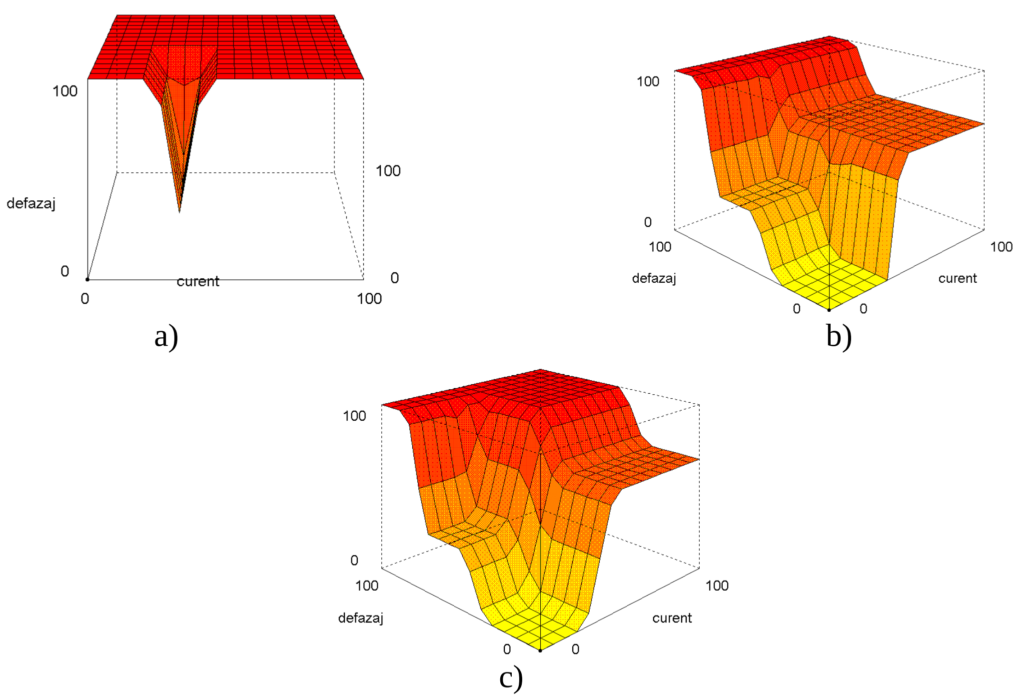
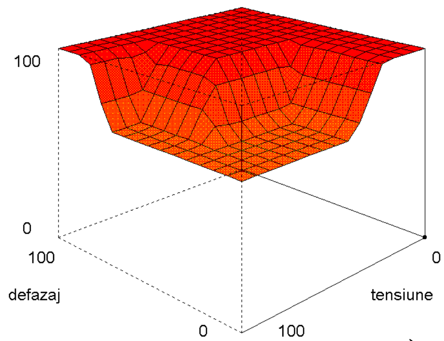
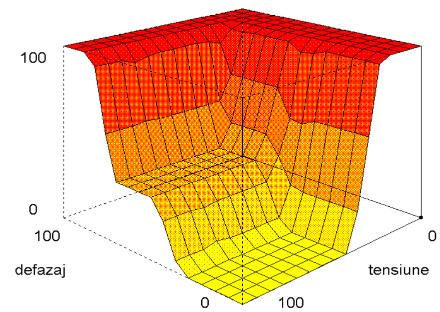


Fig. 2.3.26 “Phase shift” – “current” command surfaces for different constant values of “voltage” variable

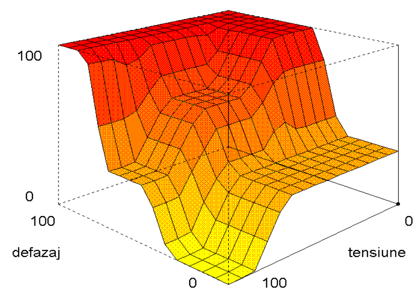
In figures 2.3.27 the surface characteristics are represented for “voltage” and “phase shift” variables, considering “current” as parameter, i.e. three values: shortcircuit, normal and overload.



a)



b)



c)

Fig. 2.3.27. “Phase shift” – “voltage” command surfaces for different constant values of “current” variable

The interpretation of these characteristics is simple and can be observed that they are totally corresponding to the inference table. It can be affirmed that the designed algorithm permit to analyze any real situation from power distribution of railway substation.

Simulation of fuzzy system functioning

The functioning correctitude of the fuzzyfication-defuzzyfication mechanism was verified using Matlab – Simulink environment. In this scope the fuzzy system was implemented in Matlab. Combinations of the input variables were random generated and the command was obtained for each resulting combination. As a result of simulation, it has been found that the designed fuzzy system is functioning correctly, so it can be implemented on a real controller. XFuzzy, Matlab and Matlab – Simulink environments were used for realizing the design functioning analyzing of the fuzzy system.

Fuzzy Controller

In order to apply the fuzzy control principles, two methods are possible:

- using a PC with A/N input interface and N/A output interface and realizing a program (usually in C^{++} language) in order to process in minimum time the imposed elements. The method was applied at the beginning of the fuzzy regulation. In present, this method is used for study and simulation in Matlab environment.

- Designing a specialized controller which will have an autonomous function or interconnected to a PC and which can be built in the nearby of the installation. In this way high performances can be obtained at the lowest prices. This controller can be connected to the programmable automates and ensure the controlling of the entire process.

In this work the second method is used. In this case, an essentially supplementary condition must be accomplished: the computing speed must be high enough in order the command element to be elaborated into a very short time, by order of μs.

Analyzing the various devices, the conclusion is that the developing system eZdsp TMS320F2812 made by Spectrum Digital USA satisfies the entire imposed conditions.

Hardware implementation and testing for the fuzzy logic relay for railway protection

The development cycle is based on three stages. In the first stage the fuzzy logic relay is designed and tuned on Matlab – Simulink using a Simpower System Model of the railway TS because the testing in the real system would have been extremely expensive and dangerous. This allows the simulation, parameters tuning and optimization of rules data base.

In the second stage, the final structures of the fuzzy logic operations are prepared for hardware implementation. In order to achieve a high speed operation some hardware specific features of the DSP are employed to reduce the computation resources for the application. One operation that requires intensive computation is the deffuzification that need complex instruction. Each input, “voltage”, “current” and “phase shift”, is sampled using an 8 bit ADC. The input variables are quantified in order to obtain the degree of membership of each point of the input for each fuzzy set. For each point is associated an index value corresponding to the membership function. The rule base in coded using the same index system active membership functions with the corresponding part of the rule base.

Finally, the structure of the system operation is coded using Code Composer Studio development environment in C. The resulting assembly code is optimized for speed in order to have the shortest cycle time. For the hardware implementation we have considered a Spectrum Digital DSP development board with TMS320F2812 processor. From the point of view of computation resources this can offer sufficient processing speed in order to meet the application requirement at a reasonable development time, since no assembly coding was necessary. This hardware solution used to implement the fuzzy logic relay structure is simple and provides good performance/price output.

The development stage was realized with the TMS320F2812 DSP board. This was important in order to identify the reaction time and manual verification of the fuzzy rule base, because it was used different values for the input signals: “voltage”, “current” and “phase shift”.

After manual checking of the correct functioning of the DSP fuzzy processor, the entire system was tested in real TS, in parallel with the existing protective system.

2.3.3.2. Fuzzy logic application for monitoring and maintaining optimum environmental conditions in a fir saplings tree greenhouse

This application has been carried out in the laboratory and aimed at designing a system with fuzzy logic to maintain optimal conditions for development of fir saplings in a greenhouse. The proposed fuzzy system uses a DSP development board built TMS 320 F2812. Researches were published in [Pănoiu M 10b] and [Pănoiu M-10e]. In a fir tree greenhouse environment conditions are more stringent than in a typical greenhouse in all aspects. In such a greenhouse the most sensitive conditions refer to soil humidity, air humidity and air temperature. The proposed system allows acquisition informations about soil humidity, air humidity and air temperature. Depending on these, the system sends three output commands. These commands are generated by using fuzzy logic**.** The optimal values in a fir tree greenhouse are:

- Soil humidity must have the values between 50% and 80 %
- Environmental temperature must have the values between 10°C and 35°C
- Air humidity must have the values between 70% and 90 %.

To obtain the optimum values for the environmental conditions it is required an integrated system to maintain soil humidity, air humidity and ambient temperature in the limits mentioned above. This is proposed to be carried out by a DSP development board with TMS 320 F2812. This board is a stand-alone card allowing to the users to examine the TMS 320 F2812 digital signal processor (DSP) to determine if it meets their application requirements. In figure 2.3.28 it is presented the block diagram for the three inputs measure: air humidity, soil humidity and ambient temperature. A fir saplings tree greenhouse effect works only in cold weather. In October are cut branches from mature trees. These branches are planted in an appropriate soil and up to March – April the braches development roots and can be planted in another outdoor greenhouse. Because the greenhouse effect works only in cold weather is not needed to air cooling. So, the three commands that are generated by fuzzy logic are:

- Soil wetting command for maintaining appropriate soil humidity
- Air warming for maintaining an appropriate ambient temperature
- Steam spray for maintaining an appropriate ambient humidity

The proposed system that allows generating these commands is presented in figure 2.3.28.

Ambient temperature measuring

For ambient temperature measurement it was used the scheme from figure 2.3.29. Bridge consisting of R1, Rv1, R2, R3 and LM335 temperature sensor provides a proportional voltage to temperature witch is amplified by integrated circuit with two operational amplifiers LM4558C. This is used for zero scheme calibration through Rv1 and the amplification is adjusted with Rv2. The variation range for ambient temperature is 0 ÷ 40 °C. It was used two operational amplifiers with high input impedance. O1 is a repeater circuit. Capacitor C4 is used for noise cancellation.

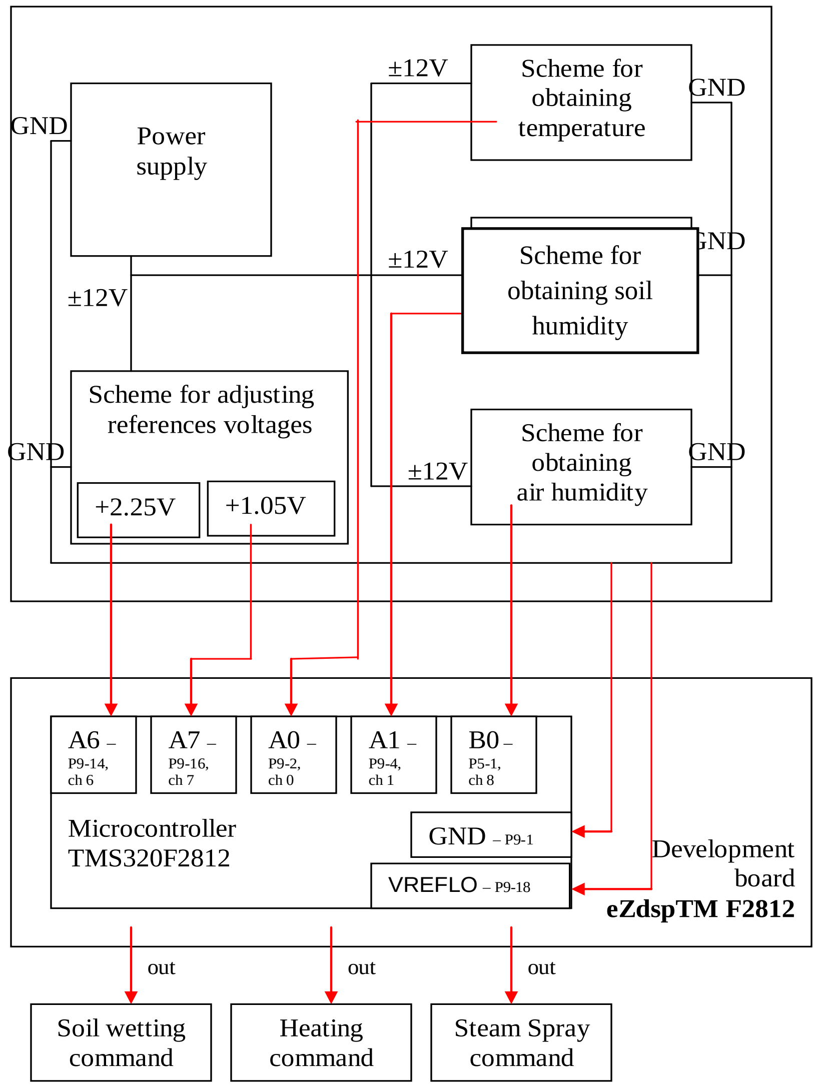


Fig. 2.3.28 The block diagram for inputs measuring and for outputs generation

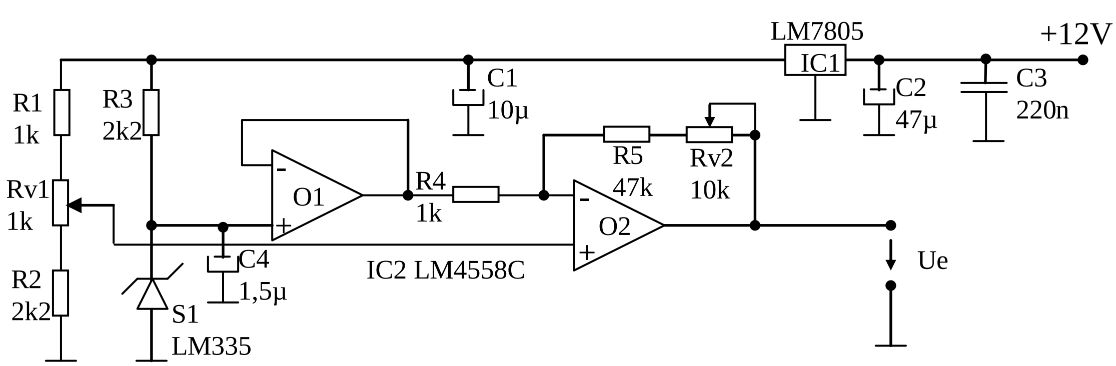


Fig. 2.3.29. Electronic scheme for ambient temperature

Soil humidity measuring

For soil humidity measuring it was used scheme from figure 2.3.30. In this scheme it was used the same elements as for the air temperature measurements: integrated circuit LM4558C with two operational amplifiers, integrated circuit LM7805, which were detailed at temperature measurement and two stainless steel electrodes witch are placed in the soil at a constant distance. The constant distance between the electrodes assures correct information about the soil humidity.

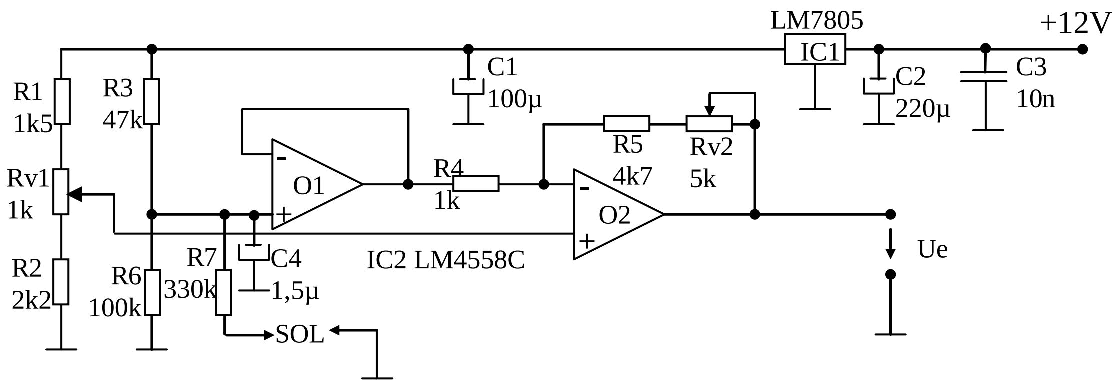


Fig. 2.3.30 Electronic scheme for soil humidity

Range of variation of soil humidity for saplings of pine is 70 ÷ 95 %, so it needs high humidity, but the domain 0 ÷ 100 % was taken into consideration.

Ambient humidity measuring

For measuring air humidity we used scheme from figure 2.3.31. It was used air humidity sensor SY –HS – 230. This air humidity sensor is designed to measure relative humidity as an output voltage witch depends on measured humidity. It is suitable for wet and dry air.

Output signals obtained from the three measurement schemes are in the range 0 ÷ 3.3 V. This is the interval that data can be purchased by the digital to analog convertor that is placed on EzDsp TMF2812 development board.

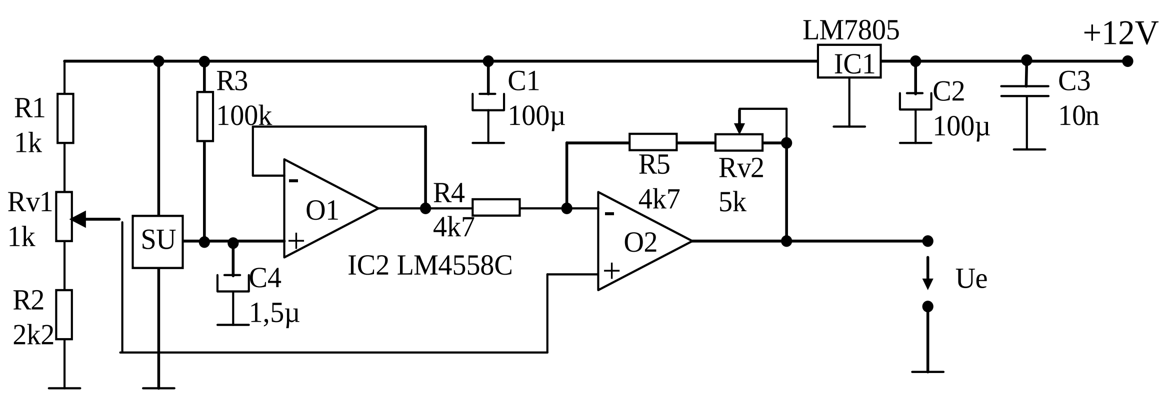


Fig. 2.3.31 Electronic scheme for air humidity

According to data acquired for soil humidity and air humidity, respective for ambient temperature will be sent the three output commands throw GPIO pins (General Purpose Input Output pins). Scheme to generate output commands throw GPIO pins is presented in figure 2.3.32.

For each of the three output commands are four levels that can be used:

- blocked – when the input values situate in normal limits
- level1 – when is needed a correction, but not very large
- level2 – when is needed higher correction
- maximum – when the input values must be influenced to go in normal limits because otherwise saplings pine will not survive.

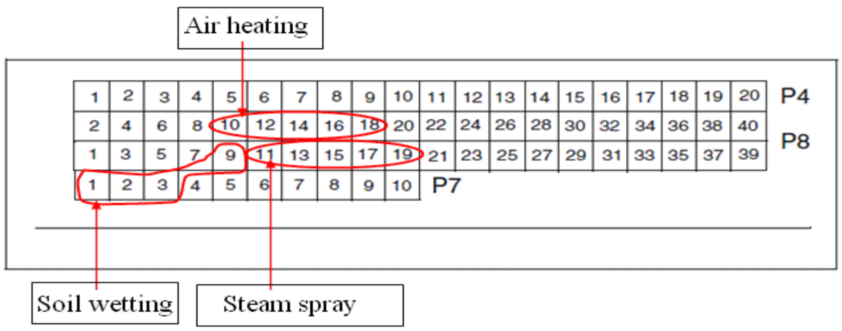


Fig. 2.3.32. Output commands generating through the GPIO pins

The proposed system based on fuzzy logic

The implemented system uses three inputs and three outputs that will ensure optimal conditions of environment and soil in a greenhouse for trees seedlings.

Input values are shown in paragraph above and they are ambient temperature, air humidity, soil humidity. The outputs, also described in paragraph above are: soil wetting, air heating and steam spray. The most common shape of membership functions is triangular, although trapezoidal and bell curves are also used. In our case trapezoidal functions were used for all three sizes of inputs and for the output sizes singleton-type functions were used.

Definition of ambient temperature fuzzy sets

Considering that the optimum temperature for proper development of fir saplings tree is between Tmin and Tmax, i.e. 10°C ÷ 40°C, the fuzzy sets were defined as in figure 2.3.33. Trapezoidal functions were chosen for membership functions.

Definition of air humidity fuzzy sets

Considering that the optimum air humidity for proper development of fir saplings tree is between AHmin and AHmax, i.e. 50% ÷ 70%, the fuzzy sets were defined as in figure 2.3.34. Trapezoidal functions for the membership functions were also chosen.

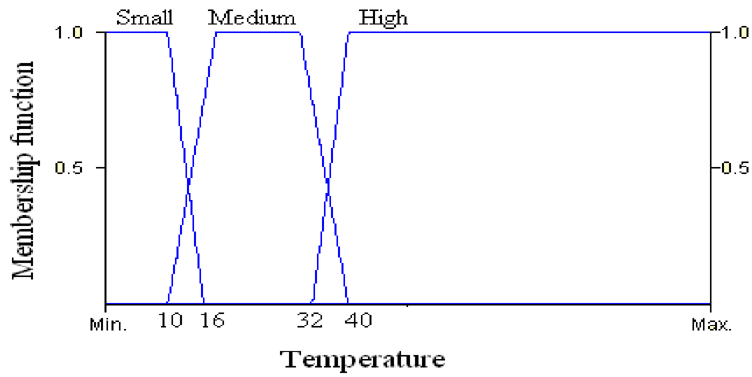


Fig. 2.3.33. Definition of ambient temperature fuzzy sets

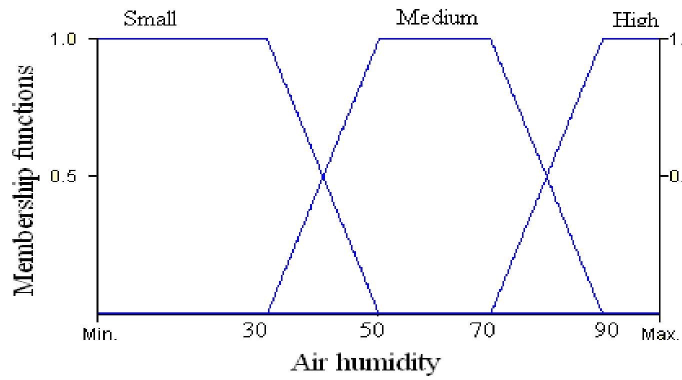


Fig. 2.3.34. Definition of air humidity fuzzy sets

Definition of soil humidity fuzzy sets

Considering that the optimum soil humidity for proper development of fir saplings tree is between SHmin and SHmax, i.e. 75% ÷ 95%, the fuzzy sets were defined as in figure 2.3.35. Like for the other two inputs, trapezoidal functions for the membership functions were chosen.

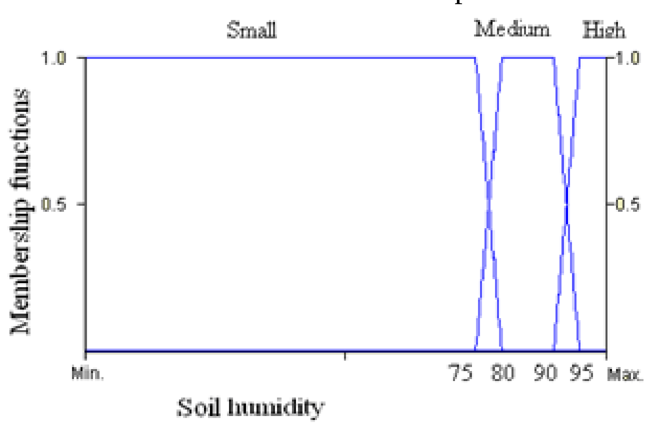


Fig. 2.3.35. Definition of soil humidity fuzzy sets

Definition of the three outputs fuzzy sets

In case of all three outputs two methods for fuzzy sets definition were used: singleton-type functions that can be seen in figure 2.3.36, i.e. the functions proposed by the Sugeno defuzzification method and trapezoidal functions in case of use the Mamdani defuzzification method.

Using these fuzzy sets, three sets of rules can be defined for the three outputs.

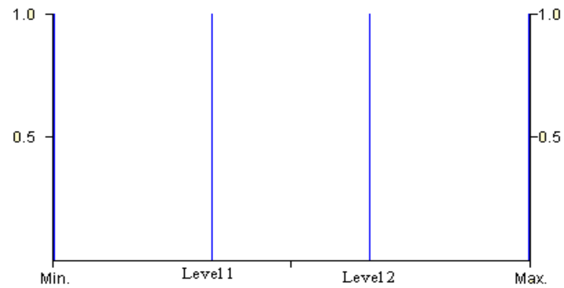


Fig. 2.3.36. Definition of the output commands

Simulation of the proposed system

In order to make the initial checking of the proposed system, a simulation system based on fuzzy logic was developed. The simulation was implemented in simulation software Xfuzzy a development environment for fuzzy-inference-based systems composed of several tools that cover the different stages of the fuzzy system design process, from their initial description to the final implementation. Thus the proposed system was implemented in Xfuzzy as shown in figure 2.3.37.

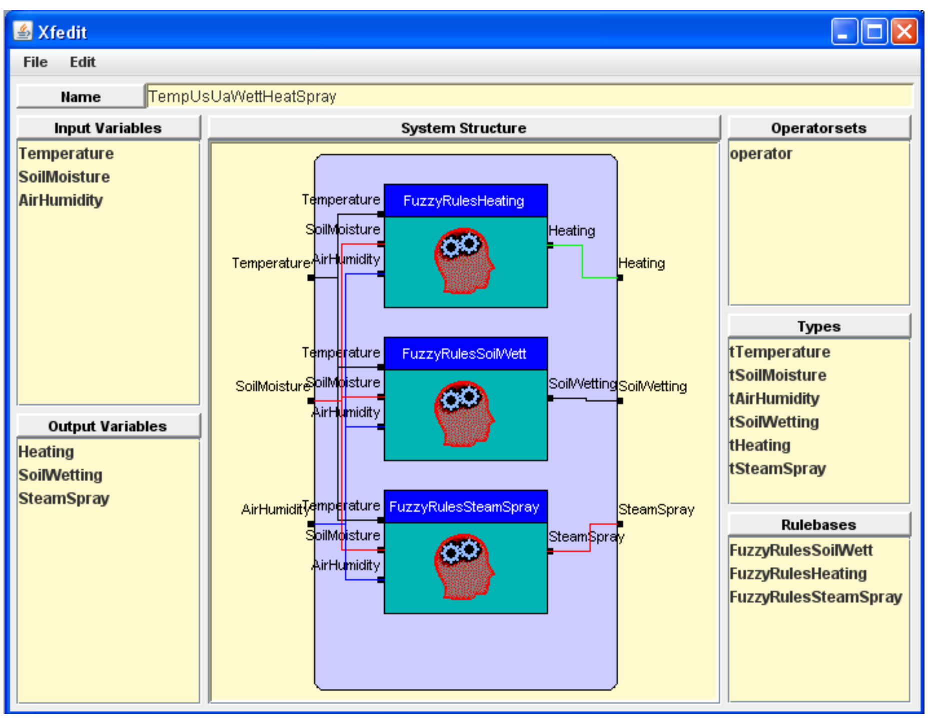


Fig. 2.3.37 Implementation of the proposed fuzzy system in Xfuzzy

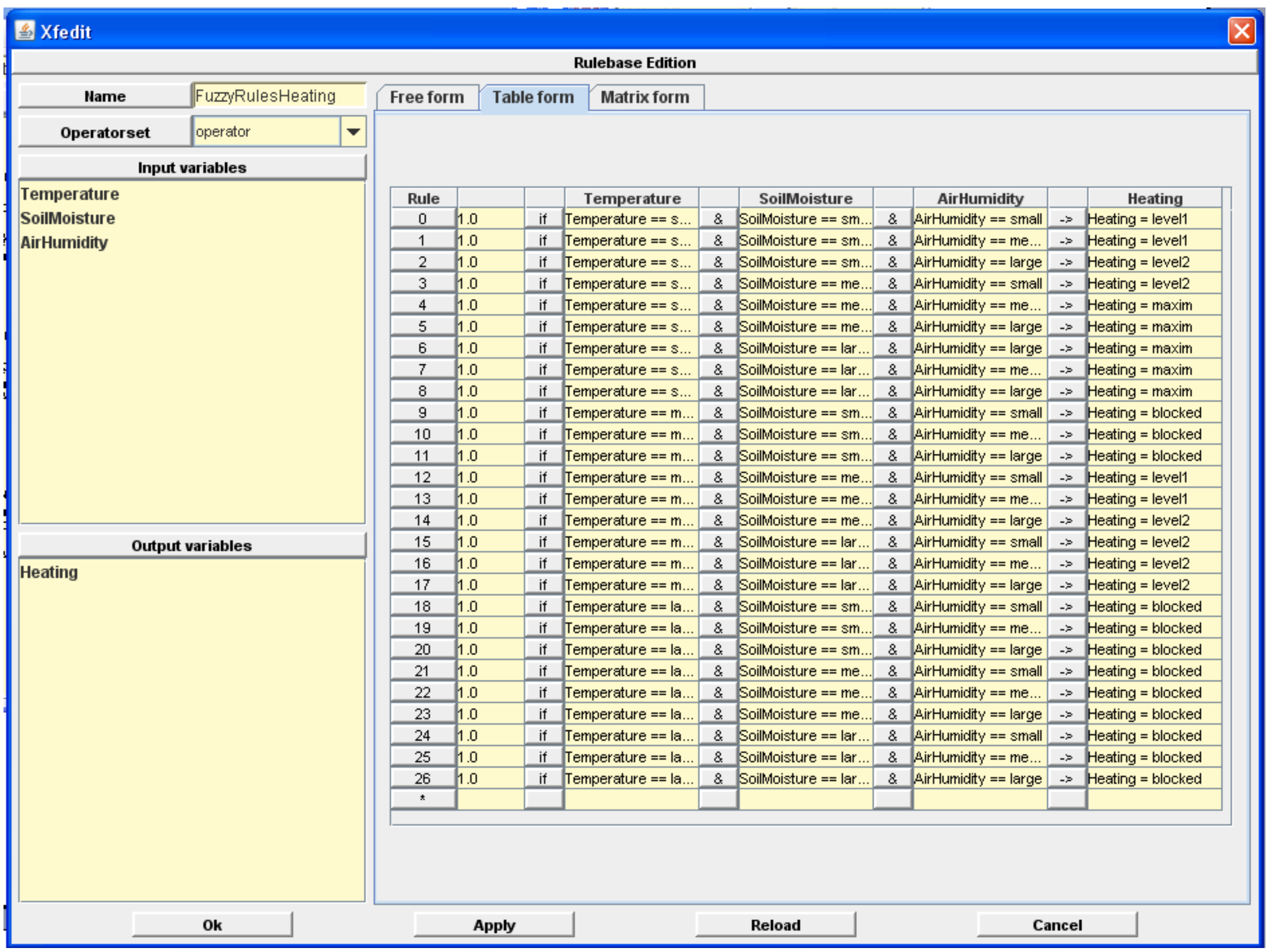
Xfuzzy simulation software allows a complete system monitoring functionality. For the output values, the sets of rules are defined as it is shown in figure 2.3.38, 2.3.39 and 2.3.40. The rules have been established for practical reasons after having consulted experts in maintain optimum environmental conditions in a fir tree greenhouse. For the other two outputs the fuzzy set of rules are defined in the same manner.

Simulation allows the monitoring operation, as shown in figure 2.3.41, 2. 3. 42 and 2.3.43. During the simulation it can be modify the temperature, the soil humidity and the air humidity. In figure 2.3.43 it can be observed how the rules are activating during modifying the inputs. In figure 2.3.44. it can be analyzed the surface plot for the system.

Implementation for the proposed system using the EZDSP TMS320 F2812

In order to realize the proposed system, using the development board EZDSP TMS320 F2812, the inputs to three channels of the development board were connected.

According to data acquired for soil humidity, air humidity and ambient temperature, the three output commands through GPIO pins will be activated.



Rule			Temperature		SoilMoisture		AirHumidity		Heating
0	1.0	if	Temperature == s...	&	SoilMoisture == sm...	&	AirHumidity == small	->	Heating = level1
1	1.0	if	Temperature == s...	&	SoilMoisture == sm...	&	AirHumidity == me...	->	Heating = level1
2	1.0	if	Temperature == s...	&	SoilMoisture == sm...	&	AirHumidity == large	->	Heating = level2
3	1.0	if	Temperature == s...	&	SoilMoisture == me...	&	AirHumidity == small	->	Heating = level2
4	1.0	if	Temperature == s...	&	SoilMoisture == me...	&	AirHumidity == me...	->	Heating = maxim
5	1.0	if	Temperature == s...	&	SoilMoisture == me...	&	AirHumidity == large	->	Heating = maxim
6	1.0	if	Temperature == s...	&	SoilMoisture == lar...	&	AirHumidity == large	->	Heating = maxim
7	1.0	if	Temperature == s...	&	SoilMoisture == lar...	&	AirHumidity == me...	->	Heating = maxim
8	1.0	if	Temperature == s...	&	SoilMoisture == lar...	&	AirHumidity == large	->	Heating = maxim
9	1.0	if	Temperature == m...	&	SoilMoisture == sm...	&	AirHumidity == small	->	Heating = blocked
10	1.0	if	Temperature == m...	&	SoilMoisture == sm...	&	AirHumidity == me...	->	Heating = blocked
11	1.0	if	Temperature == m...	&	SoilMoisture == sm...	&	AirHumidity == large	->	Heating = blocked
12	1.0	if	Temperature == m...	&	SoilMoisture == me...	&	AirHumidity == small	->	Heating = level1
13	1.0	if	Temperature == m...	&	SoilMoisture == me...	&	AirHumidity == me...	->	Heating = level1
14	1.0	if	Temperature == m...	&	SoilMoisture == me...	&	AirHumidity == large	->	Heating = level2
15	1.0	if	Temperature == m...	&	SoilMoisture == lar...	&	AirHumidity == small	->	Heating = level2
16	1.0	if	Temperature == m...	&	SoilMoisture == lar...	&	AirHumidity == me...	->	Heating = level2
17	1.0	if	Temperature == m...	&	SoilMoisture == lar...	&	AirHumidity == large	->	Heating = level2
18	1.0	if	Temperature == la...	&	SoilMoisture == sm...	&	AirHumidity == small	->	Heating = blocked
19	1.0	if	Temperature == la...	&	SoilMoisture == sm...	&	AirHumidity == me...	->	Heating = blocked
20	1.0	if	Temperature == la...	&	SoilMoisture == sm...	&	AirHumidity == large	->	Heating = blocked
21	1.0	if	Temperature == la...	&	SoilMoisture == me...	&	AirHumidity == small	->	Heating = blocked
22	1.0	if	Temperature == la...	&	SoilMoisture == me...	&	AirHumidity == me...	->	Heating = blocked
23	1.0	if	Temperature == la...	&	SoilMoisture == me...	&	AirHumidity == large	->	Heating = blocked
24	1.0	if	Temperature == la...	&	SoilMoisture == lar...	&	AirHumidity == small	->	Heating = blocked
25	1.0	if	Temperature == la...	&	SoilMoisture == lar...	&	AirHumidity == me...	->	Heating = blocked
26	1.0	if	Temperature == la...	&	SoilMoisture == lar...	&	AirHumidity == large	->	Heating = blocked
*									

Fig. 2.3.38. Definition of air heating set of rules

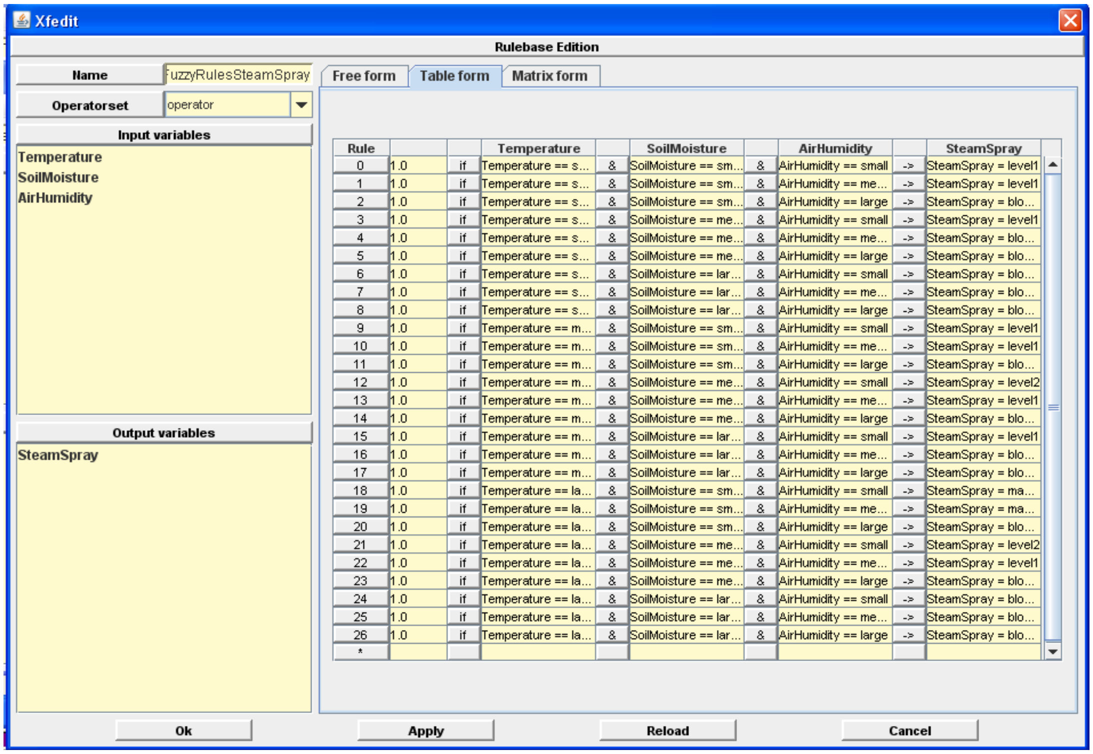


Fig. 2.3.39. Definition of steam spray set of rules

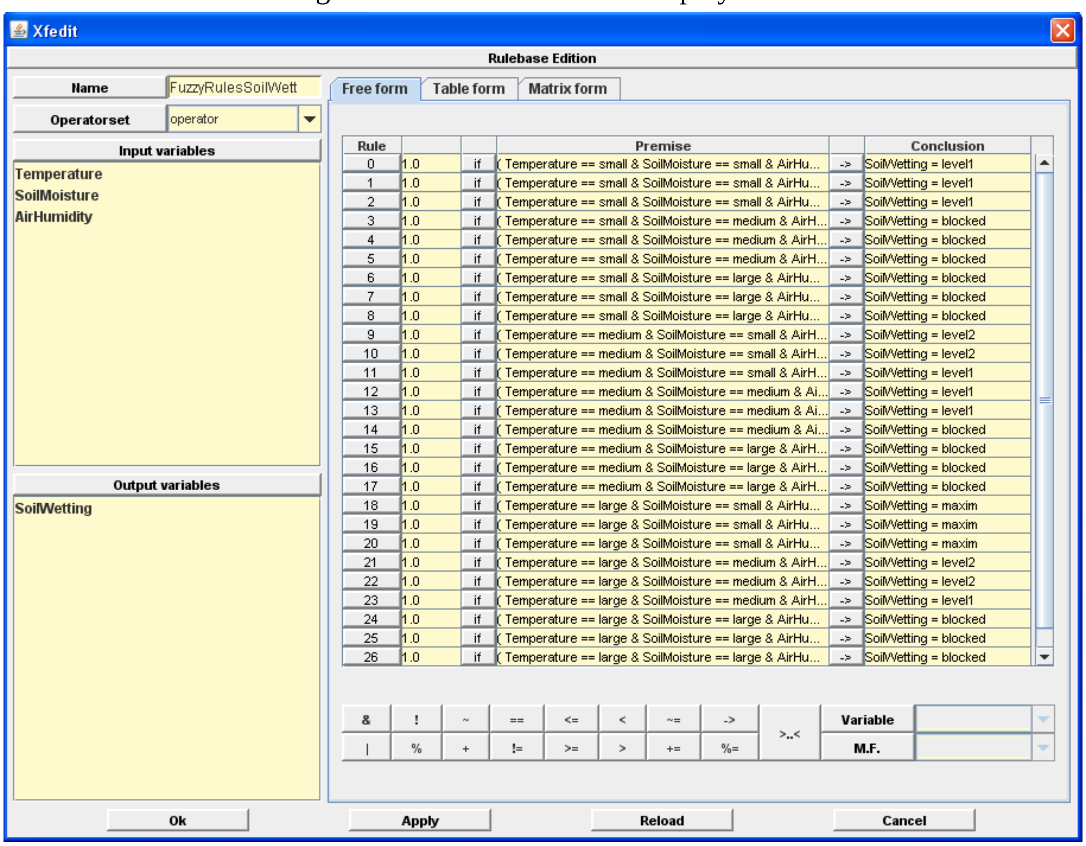


Fig. 2.3.40. Definition of soil wetting set of rules

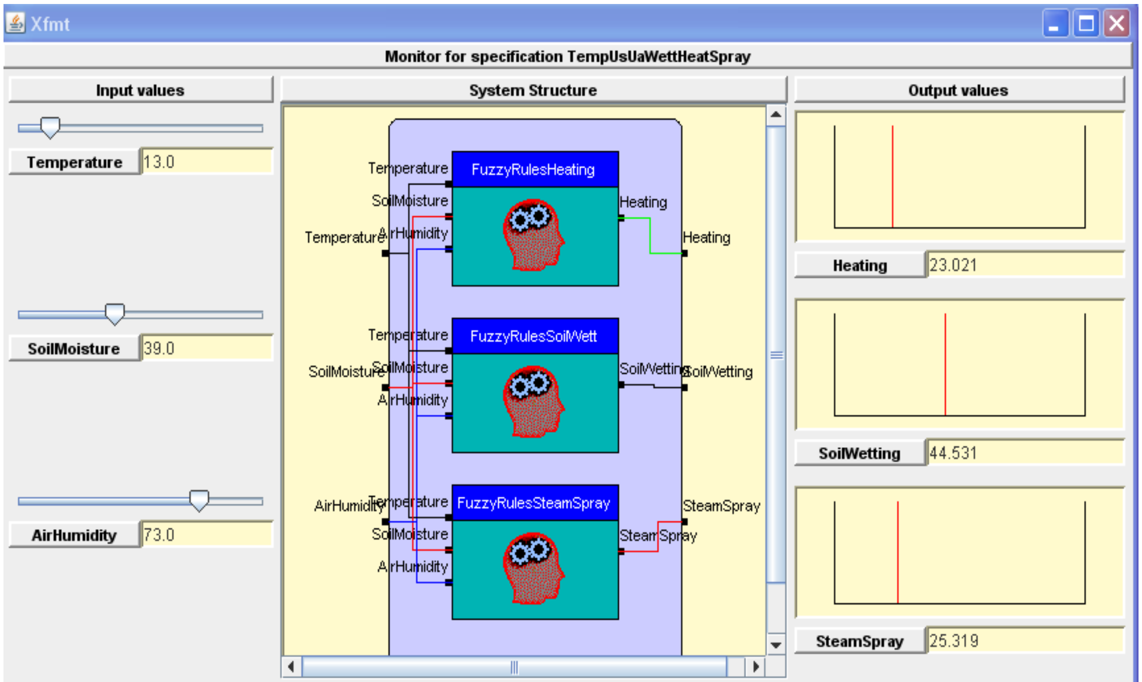


Fig. 2.3.41. Monitoring the Xfuzzy system

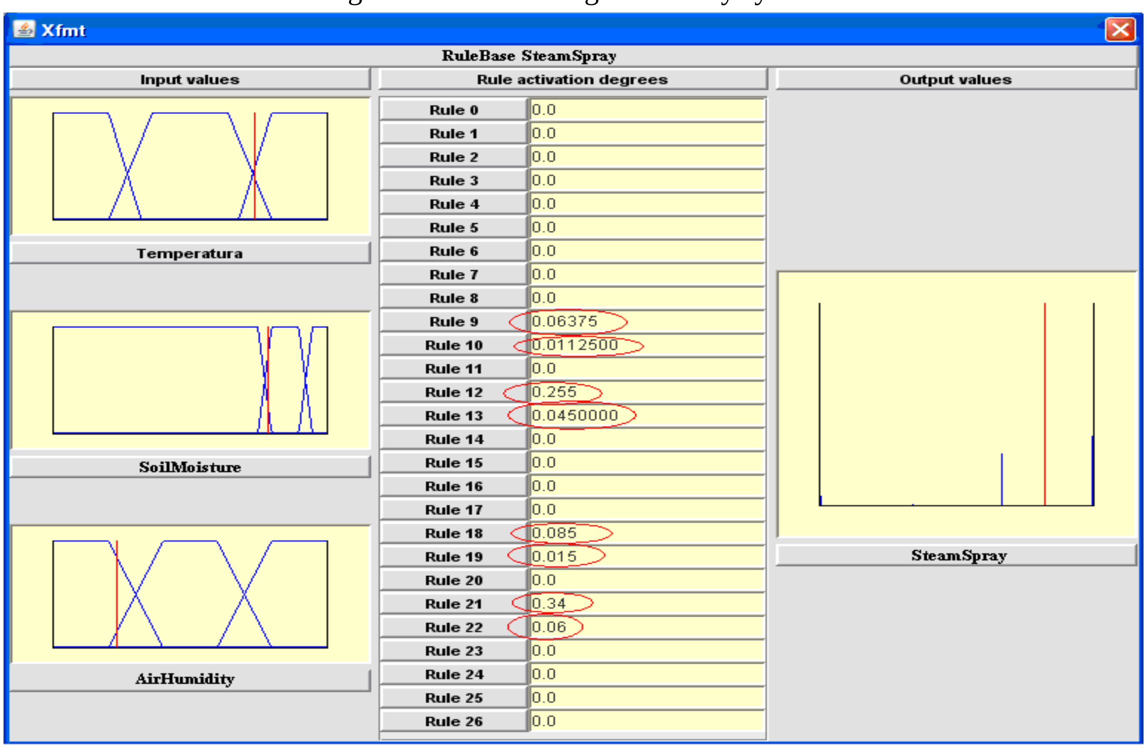


Fig. 2.3.42. Rules monitoring for the proposed system for steam spray in case of Sugeno defuzzification method

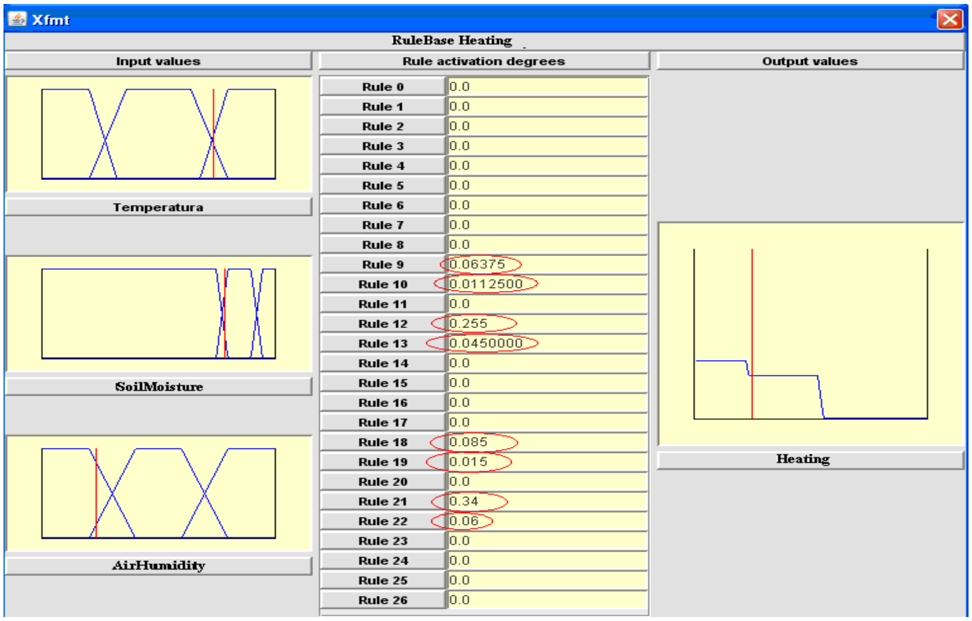


Fig. 2.3.43. Rules monitoring for the proposed system for heating in case of Mamdani defuzzification method

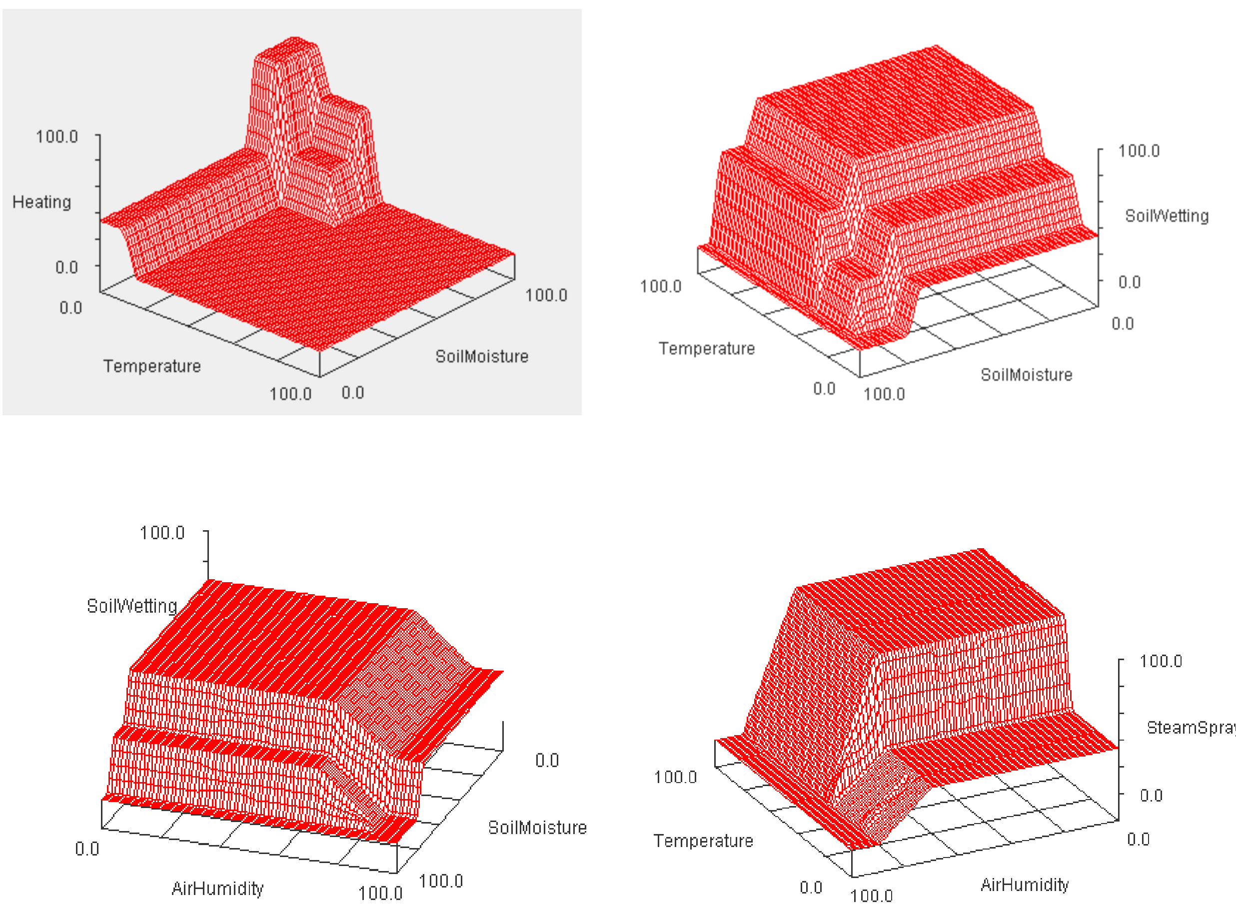


Fig. 2.3.44. The surfaces plot for the system

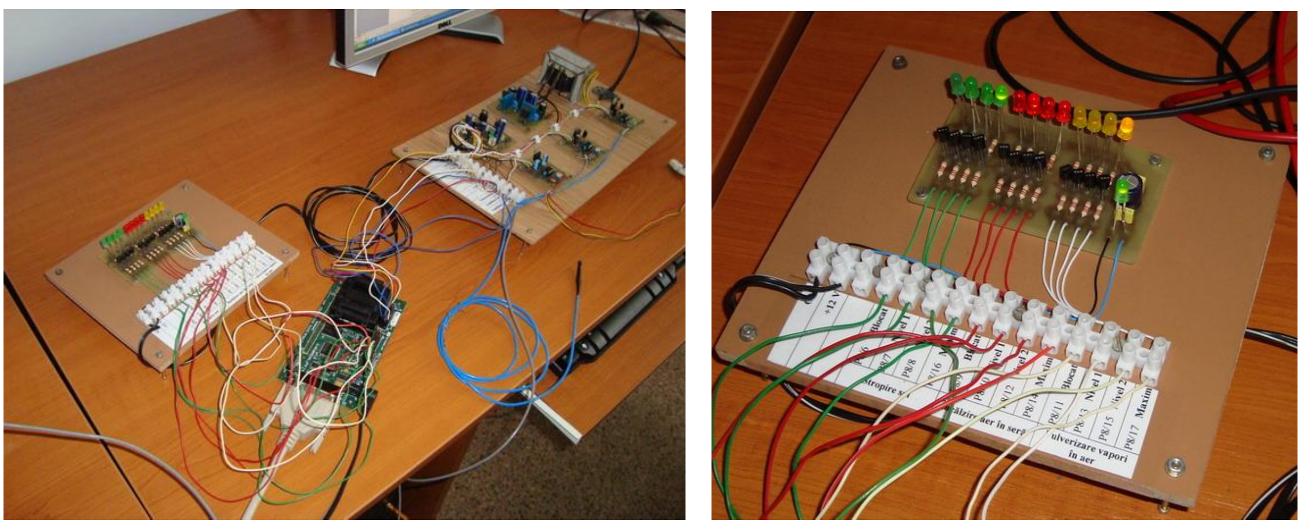
For implementing the fuzzy rules and to generate the output commands, a program was implemented in C language using Code Composer Studio. Code Composer Studio v4 (CCS v4) is the integrated development environment for TI's DSPs, microcontrollers and application processors.

In order to verify the functioning of the proposed system, 9 LEDs were connected to the output pins of the development board. The number of 9 LEDs result by taking into account that for each of three outputs there are three levels for the output command, level 1, level 2 and maximum level. In figure 2.3.45 a) the proposed system realized with EzDSP TMS320 F2812 is presented.

In figure 2.3.45 b) it can be seen the proposed system during functioning. In this case, the soil wetting and steam spray are reaching the maximum level and the heating air is blocked.

In the practically situations, decision makers are often faced to a plurality of objectives and constraints in a world of imprecise data about the preferences of agents, the local constraints and the global environment. For these reasons, systems based on fuzzy logic like the proposed system, are simple and much easier to implement.

The simulation software, Xfuzzy is also very useful for rule set definition and for testing the proposed system. Texas Instruments TMS320F2812 DSP is ideally suited for fuzzy logic implementation. This chip may be used to produce low cost, high performance applications in a fraction of the time of conventional PID controllers.



a) b)

Fig. 2.3.45. a) The fuzzy system implemented using EzDSP TMSF2812. b) Monitoring the outputs during system functioning

2.3.4. Other research in the artificial intelligence field

2.3.4.1. Applications of artificial neural networks in industry

Some researches regarding control of the continuous casting process using Artificial Neural Networks, ANN, was presented in [Tirian 09] This paper work refers to coming up with a control method for the continuous cast process by using a neural system of crack detection, which may lead to remove all the cover cracking and factory rejects caused by this phenomenon. The output signal of the neuronal network causes an improvement of the water flow used for primary cooling of the casting speed, in case it predicts any crack. A model of the artificial neural network of the type of multiplayer perceptron is adopted, because this type of network is efficient in recognizing patterns. It was established that when a crack occurs, the liquid steel touches the crystallizer wall, causing temperature increasing.

Another application of Artificial Neural Networks in industry is in control of the CNC metal plate-cutting machine. The numeric command machines are very much used in industry. The application which the candidate participated in the research team refers to an automatic selection of the oxygen pressure for a numerical control metal plate-cutting machine. In [Tirian 13] a system based on artificial neuronal network is proposed in order to select automatically the oxygen pressure for a CNC metal plate-cutting machine. The system analyzes the cutting metal and its depth angle regulates the oxygen pressure. Proposed system uses a layer perceptron artificial neural network. The input values are sampled and transmitted to 6 buffers, being stocked on 6 stocking units. The neural network receives at the input the maximum of the 6 values. The network training was realized using Levenberg – Marquardt method, because that it grants a swift convergence as compared to other algorithms under test.

2.3.4.2. Research regarding text to speech systems (TTS)

In this study the candidate as part as a team propose to study the possibilities of transforming the written language into speech (text-to-speech) using the LabVIEW programming environment.

To this aim were studied text-to-speech interfaces provided by the Microsoft Speech SDK for TTS applications. The number and diversity of languages that can be used through these interfaces was also taken into consideration. The emphasis will be on the advantages and the limitations of each class while analyzing the possibility of rendering languages that use special characters.

Two applications implemented in LabView were presented in [Pănoiu M 14c]. The first application is a TTS designed and implemented in LabVIEW using the ITextToSpeech interface and a number of Lernout & Hauspie languages. The application use an ActiveX control that wraps up the high level Voice Text API. The second application is a TTS implemented by technologies (eSpeak, MBROLA) other than the above-mentioned interfaces.Following the researches in this area We have obtained some conclusions: Complications arise when we want to build a TTS for a specific language or a particular voice quality. Question arises as to the character encoding in that language and whether there is software commercially available for that language. The answers all depend on what exactly one wants to achieve through the application. Designing a TTS that can accurately render special language characters in LabVIEW was a very complicated task to undertake, given the limitations of the programming environment. However, we have demonstrated that the task of building a TTS in LabVIEW with special character recognition is not impossible and, in the process, that LabVIEW is a highly versatile programming environment. If LabVIEW libraries are too restrictive for the needs of the application one can use methods other than classical ones for solving the challenges.

2.3.4.3. Research in the field of multi-agent systems based on asynchronous search techniques in the programming with distributed constraints

In addition to this research, the candidate participated as a member of a research team with the Constraint programming and Multi-Agent Systems topics.

The asynchronous searching techniques are characterized by the fact that each agent instantiates its variables in a concurrent way. Then, it sends the values of its variables to other agents directly connected to it by using messages. These asynchronous techniques have different behaviors in the case of delays in sending messages. The paper [Muscalagiu 08] presents the opportunity for synchronizing the execution of agents in the case of asynchronous techniques. It investigates and compares the behaviors of several asynchronous techniques in two cases: agents process the received messages asynchronously (the real situation) and the synchronous case, when a synchronization of the execution of agents is done, i.e. the agents perform a computing cycle in which they process a message from a message queue. After that, the synchronization is done by waiting for the other agents to finalize the processing of their messages. The experiments show that the synchronization of the agents execution leads to lower costs in searching for solutions. A solution for synchronizing the agents execution is suggested for the analyzed asynchronous techniques.

In [Muscalagiu 09a] a general implementation and evaluation model with synchronization and support for message management in Netlogo, for the asynchronous techniques is proposed. This model will allow the use of the NetLogo environment as a basic simulator for the study of asynchronous search techniques. This model can be used in the study of the agents' behavior in several situations, like the priority order of the agents, the behavior in the synchronous and asynchronous case and, therefore, leading to the identification of possible enhancements in the performances of asynchronous search techniques. Starting from the proposed implementation model, two multi-agent systems with synchronization which can be used for the implementation and evaluation of the asynchronous techniques that can run on a single computer are described.

The asynchronous searching techniques are characterized by the fact that each agent instantiates its variables in a concurrent way. Then, it sends the values of its variables to other agents directly connected to it by using messages. The paper [Muscalagiu 11] presents the opportunity for synchronizing the execution of agents in case of asynchronous search techniques. It investigates and compares the behaviors of several asynchronous techniques in two cases: agents process the received messages asynchronously (the real situation) and the synchronous case, when a synchronization of the execution of agents is done. In [Muscalagiu 11] is studied the effect of synchronization of agents' execution in random binary problem. Experiments with asynchronous search techniques are standardly conducted on randomly generated networks of constraints. Experimental results illustrate that the synchronization is more effective for several families of asynchronous techniques.

Another paper, [Muscalagiu 13] presents an application in bioinformatics of multi agent systems. The protein folding problem is one of the most challenging problems in current biochemistry and is an important problem in bioinformatics. All current mathematical models of the problem are affected by intrinsic computational limits. The previous research offers few approaches that make use of multi-agent systems to resolve this problem. In this paper we present an agent-based framework for protein structure prediction, composed by autonomous agents which collaborate in order to find a solution using Distributed Constraint Programming (DisCSP/DisCOP). The amino acids of an input protein are viewed as an autonomous agent that communicates with others by transmitting messages. It was analysed the NetLogo environment with the purpose of building a general model of implementation and simulation for the protein structure prediction. Starting from the proposed implementation model with lattice models based on distributed constraints, [Muscalagiu 13], is presented a multi-agent systems which can be used for the implementation and simulation of the protein structure prediction, which can run on a single computer or on a cluster computing environment. The version of the tool presented herein allows studying and exploring complex problems belonging principally to structural biology, such as protein folding.

2.4. CONTRIBUTIONS TO INTERACTIVE EDUCATIONAL SOFTWARE DEVELOPMENT

After graduation of PhD stage, the candidate was part of a team that has implemented a series of interactive educational software systems. These systems have been used and are still used in present in computer-aided instruction field. The team in which the candidate was part has harnessed the efforts for the realization of these information systems through the publication of works in which are presented the most significant of the educational software systems. These publications are summarized in this chapter.

At the intersection of computer science with the educational field, a programmed instruction and a particularly promising variant was profiled. It was obtained by the use of computers, for educational purposes. It resulted computer assisted training, which is a new dimension to training and involving global rethinking of the education process, adapting it to the new possibilities offered by the computer. For the analysis and design of the interactive software it was used UML and CASE environment applied for diagrams representation it was ArgoUML. The use of the UML modelling language for the creation of the diagrams is characterized by rigorous syntactic, rich semantic and visual modelling support. Interactive software implementation was achieved through two programming languages: Java and C++.

2.4.1. Contributions to interactive educational software development for study issues in Electrical Engineering and Computer Science

The paper [Pănoiu C 10a] presents a software package, which can be used as educational software, for study the power electronics. This study deals with the simulation of power electronic circuits by using PSCAD-EMTDC software. Since the equations and functions can be represented using embedded components from PSCAD-EMTDC library or embedded custom components defined by user, simulation method is simple and versatile. The PSCAD-EMTDC simulates the functioning of single and three-phase rectifiers, PWM choppers and inverters, AC choppers and other power electronics devices. The study is useful for obtaining a quick solution for power electronic devices and for more complex systems containing power electronic circuits.

In [Pănoiu M 09b] is described the visual environment for learning the basics of computer science: the binary and hexadecimal numeration systems and how the information in the computer memory is represented. This system is an interactive programming environment with graphical user interface that has a friendly user interface and logic of usage. It offers all of the essential functions needed to understand the basics of binary, octal and hexadecimal numeration systems, and the conversion between these systems. The software offers also options needed to understand the two's complement code, the floating point numbers single and double precision. The software was implemented in Java language.

The papers [Pănoiu M 10a] and [Pănoiu M 10d] present an educational software package implemented in Java which shows and analyzes through visual simulation some well known sequential and parallel algorithms. It was study the memory access for PRAM model and some known algorithms for PRAM model. It was analyze also the most known sorting algorithms and the main graph algorithms in both sequential and parallel variants. It was also performed a comparative study between a classic sequential algorithm and a parallel algorithm in terms of execution times. The software is very useful to both students and teachers because the computer science especially computer programming is difficult to understand for most of the students. By using visual simulations in computer assisted learning, the efficiency of learning is increased. There are some subjects in fundamentals of computer science like sorting algorithms, parallel algorithms that are very difficult to learn and understand for some students. By using educational software these concepts are showing to the students in an attractive way, visually using animation and having the opportunity to interact with the application.

In the paper [Iordan 12a] the steps required for object oriented designing of a didactic computer system used in the study of graphical data structures were presented, particularly for understanding the algorithms used to determine the minimum spanning tree: Prim algorithm, Kruskal algorithm, Sollin algorithm, reverse-delete algorithm and linear time randomized algorithm. Use-case diagram defines the system domain, allowing visualization of the size and sphere of the action for the entire development process.

In the paper [Iordan 13a], an interactive educational software used to understand the algorithms was presented. This educational software was also used to verify if the graph is a bipartite graph or complete bipartite graph.

In the paper [Iordan 13b] the necessary steps required for object oriented implementation of new software used in the study of electrical circuits with assistance of graphs theory were presented. The software permits the determination of the spanning tree corresponding to the current graph by selecting an algorithm and de determination of cospanning tree.

In the paper [Iordan 12b] the necessary steps required for object oriented implementation of didactic software used in the study of binary trees were presented.

2.4.2. Contributions to interactive educational software development of for study issues of mathematics

In the papers [Iordan 07a], [Iordan 07b] and [Iordan 11c], a new dynamical methods for the study of the euclidian geometry was presented. The application is implemented in Java. All applets are visual and animation-oriented. Moving figures on the screen help students to grasp the meaning of mathematical ideas intuitively. Using the UML modelling language, the analysis of an informatics system consists in drawing the use case and activity diagrams. Each case describes the interaction between the user and the system. The diagram defines the system domain, allowing visualization of the size and scope of the whole developing process. For each use-case in the diagram presented earlier an activity diagram is constructed. Each diagram will specify the processes and algorithms that are behind the use cases studied.

In the papers [Iordan 08a] and [Iordan 09c], the elaboration of an educational informatics system for doing geometry on a computer was presented. In a way it replaces pencil, paper, ruler and compass with equivalent computer tools. With the mouse you “draw” in a window on screen, i.e. you place points, connect them by lines, draw perpendiculars, etc. This functionality is useful if you want to do exact constructions.

In the papers [Iordan 10b] and [Iordan 10d], the necessary stages in implementing an informatics system used for the study of computational geometry elements were presented. In the papers [Iordan 10a] and [Iordan 10c] was presented the design of an intelligent system destined for development process of demonstrating abilities for geometry theorems. This system will make available to user a proof assistant which will allow interactive vizualization of several demonstrations for the same theorem, demonstrations that have been generated by using three specific methods for automatic demonstration of theorems: area method, full-angle method and inferences accomplishment.

In the papers [Iordan 08b], [Iordan 08c] and [Iordan 09e], the elaboration of an interactive educational software for studying plane analytical geometry elements was presented.

In the papers [Iordan 09a] and [Iordan 09d], the development of an interactive educational software was presented, which is able to be used for teaching quadric surfaces like ellipsoid, sphere, hyperboloid with one sheet, hyperboloid with two sheets, hyperbolical paraboloid, elliptical paraboloid.

In the paper [Iordan 09b], a software package was presented, which can be used as educational software to the differential geometry course for presentation of the helical and revolution surfaces.

3. SCIENTIFIC, PROFESSIONAL AND ACADEMIC FUTURE DEVELOPMENT PLANS

I am currently Prof. Dr. Engineer at Department of Electrical Engineering and Industrial Informatics, at the Faculty of Engineering in Hunedoara, Polytechnic University of Timișoara.

The motion for future academic career development is divided into the following parts:

I. Elements of success in the candidate career before the habilitation application
II. Future academic career development

I. Elements of success in the candidate from previous career of candidate

A. College degree:

During the period 1984-1989 I attended to the Faculty of Electrical Engineering at the Polytechnic Institute “Traian Vuia” Timișoara, in Automation and Computers specialty.

During the five years I attended college, I have participated in various scientific students competitions and in scientific students communication sessions.

My university average graduation was 9.43 and I obtained bachelor of in Automation and Computers specialty, obtaining 10 in diploma exam.

B. Ph.D. Studies

In 1994 I was admitted to the Ph.D. studies program of the Polytechnic University of Timisoara. I finalized the Ph.D. thesis, entitled "Simulation of processes based on the modeling of the three-phase electric arc furnace installation and direct action" in 2001, in a public presentation in 2.10.2001. The title obtained is Doctor Engineer in Electrical Engineering domain.

C. Postdoctoral scientific activity

Because I am a part of a multidisciplinary research team and my field of expertise is automation and computers and also the area in which I have obtained my PhD thesis is Electrical Engineering, I have developed my research in three main areas:

- Modeling, simulation and identification applied in electrical engineering and in other fields,
- Artificial and computational intelligence applied in electrical engineering and in other fields,
- Contributions on developing of interactive educational software.

During 2002-2013 period I have published over 130 papers of which 41 (13 as first author) are indexed in the ISI Web of knowledge database and 73 in other international databases (Scopus, ACM, Inspection, Engineering Village, Google Scholar).

In the ISI Web of Knowledge database I have 28 citations (excluding self citation). In other international databases I have 77 citations (Scopus, ACM, Google Scholar).

In the aftermath of the public presentation of my doctoral thesis, I have continued research in the field of the Ph.D. thesis on the one hand and I have addressed to other interdisciplinary fields on the other hand. All these activities were detailed in Chapter 2, namely Technical presentation.

D. Teaching activity

I began teaching in 1992, when I was assistant research at the Ecological University of Bucharest – Deva branch, Hunedoara. I held this position until February 1994. During this period I taught the laboratories for the following disciplines: Programming Languages and Economic Informatics.

From March 1994 to September 1997 I held a position as research assistant in the Department of Electrical Engineering, Faculty of Engineering in Hunedoara. Within this department I taught the following disciplines: Industrial Automation (laboratory), Electrical Engineering (laboratory), Industrial Electronics (laboratory), languages and programming techniques (course and laboratory), Computer Programming (course and laboratory) and Industrial Informatics (course and laboratory).

From October 1997 to September 2002 I held a position as lecturer in the Department of Electrical Engineering, Faculty of Engineering Hunedoara. During this time I taught the following subjects: Microprocessor Systems (course), Data Structures and Algorithms (course and lab) Computer Programming (course), Object Oriented Programming (course and laboratory), Digital Equipment (course and laboratory).

From October 2002 to September 2014 I held a position as assistant professor in the Department of Electrical Engineering (until 2007) and then in the Department of Electrical Engineering and Industrial Informatics (2007 to September 2014). During this time I taught the following disciplines: Computer Programming, Object Oriented Programming, Java Programming, Artificial Intelligence, Microprocessor Systems, Multiprocessor Systems.

From October 2014 I took a position as university professor in the Department of Electrical Engineering and Industrial Informatics and I am currently teaching the following subjects: Artificial Intelligence in Electrical Engineering, Intelligent Techniques in Electrical Engineering, Java Programming, Microprocessor Systems, Knowledge Based Systems and Computer Programming.

During this period I have developed e-learning courses or course notes for all subjects. I have been using modern teaching technologies: video projector, interactive presentations, etc., since 1999 - 2000. Also, I have tried to combine theory and practice in all the subjects that I have accomplished. I exemplified applications using an interactive manner as part of both the courses and the laboratories.

In order to use the most modern learning methods available I have attended graduate courses in Blended-Learning and modern educational technologies for higher education – through the POSDRU project that took place during 2012-2013: POSDRU / 87 / 1.3 / 5/60891 - Graduate school for the initial and continuous training of teachers and trainers in the field of engineering and technical sciences - DidaTec.

In 2008 I submitted an application for the funding of a development project through ESF. This project was accepted and was funded during 2010 - 2012. The project was entitled "Partnership for conducting internships in informatics and communications". The project won the POSDRU program. The project aimed to form a partnership with an IT company, in order to achieve a higher level internship for the students from the undergraduate study program of Industrial Informatics (of whose study program I am responsible). This project has been a successful one for the Faculty of Engineering in Hunedoara, primarily for the students of Industrial Informatics, who had the opportunity to conduct an appropriate internship program. One result of the project was the equipment acquisitions made during that period, IT equipment that is currently used by the teachers of the faculty in both teaching and research activities.

The training of students also falls in the category of teaching activities in order for them to participate in competitions. Thus, for the last 10 years in which the Scientific Student Communications Session has annually developing, I have coordinated an average of 3 students per year, students who have achieved various awards.

E. Other activities in which I have participated in the Department of Electro-technology / Department of Electrical Engineering and Industrial Informatics

Being part of a number of teams of professors, I have participated in all kinds of activities: teaching, research, collaboration with other universities or firms, as well as organizational activities.

Thus, since 1996 I have been a member of the Board of the Faculty of Engineering in Hunedoara.

In 2004 I was elected Head of the Electro-technology Chair. I held this position until 2007 when the departments of the Faculty were reorganized, so the three departments became two. Following this reorganization, I have been chosen the manager of the Department of Electrical Engineering and Industrial Informatics. As Head of Chair or Department Manager, I was involved in all the activities of the chair / department.

During 2008-2012 period, I was the Head of the Department of Lifelong Learning, department that functions with extra budgetary revenue. Inside this department series of postgraduate programs are developing, which offer fundraising capabilities within the Faculty of Engineering of Hunedoara.

Since 2012 I have been in the Board of the Centre for Postgraduate Studies within the Graduate School of UPT.

I was member of the teams that are responsible for monitoring the Electromechanical and Industrial Informatics study programs. I am still responsible for the undergraduate study program of Industrial Informatics. I am also responsible for the postgraduate study program: Computer Techniques in Electrical Engineering. Regarding these two study programs I participated in all the activities related to authorization / regular assessment.

In 2013, together with other teachers in the Department of Electrical Engineering and Industrial Informatics, I have initiated a new undergraduate study program: Electrical Engineering and Computers. As the person responsible with this study program, I attended and coordinated the preparation of interim authorization file. Following the ARACIS (The Romanian Agency for Quality Assurance in Higher Education) committee visit, the authorization to operate was obtained.

Under the current Board of the Faculty I am the Head of the Curricula and Syllabi Chair. In this capacity, I have participated in all actions of monitoring the study programs.

Also since 2012, I have been on the Board of the Department of Electrical Engineering and Industrial Informatics, and in the Department Council Office. In the Council of the Department I am Head of the Teaching Committee and HR Commission.

I am also a part of the Admission Committee for Postgraduate and Undergraduate Studies of the Faculty of Engineering in Hunedoara.

II. Future academic career development

The development of my upcoming academic career will focus on three main areas:

- Teaching (educational)
- Research
- Other activities within the department / faculty

A. TEACHING

In teaching area I propose a series of actions designed to streamline the teaching / learning activity of the students. These measures include:

- Assessment of the courses at least once every three years to maintain the timeliness of their content
- Publishing courses, at least in e-learning and also in printable form. I will try to publish, in printable form, at least one course / 2 years on the following subjects:
    - Intelligent Systems in Electrical Engineering
    - Artificial Intelligence in Electrical Engineering
    - Neural networks
- Using UPT's e-learning platform for as many of the student activities as can be, in order to stimulate their active participation in educational activities.

On the subject of revising the courses I will try to adjust the content of the subject sheets (course content) to the requirements of the labor market employers. In order to accomplish this, I will keep in touch with the economic environment and I will analyze the curricula of other study programs that belong to other universities in the country or abroad.

For newly established study programs I will develop teaching materials for the subjects on which I will be holding the course; in the first stage electronically and then printed. Here I am mentioning two courses that I teach in the postgraduate study programs: Intelligent Systems in Electrical Engineering, respectively Artificial Intelligence in Electrical Engineering.

In these courses I intend to implement applications in embedded systems based on intelligent techniques (fuzzy logic, neural networks, and hybrid intelligent systems).

For all postgraduate courses I will attempt to implement available applications for the laboratory via the UPT e-learning platform. I will also try to introduce practical examples relevant to the study program within the course itself. I believe that, in this manner, the students' interest towards the subject concerned can and will be increasing.

Wherever possible, especially in postgraduate courses, but also in undergraduate ones, I plan to use various and appealing methods for the student's examinations that will engage them in problem solving behavior. This kind of examination is preferred by the students because they access to the references during the examination, although it requires more creativity from the teacher.

I intend to continue to coordinate students for participation in the scientific communication sessions which is held each year at our Faculty. I intend to coordinate minimum 3 students each year in order to participate to these sessions.

B. RESEARCH

I plan to continue research in the areas explored until the present day. The field where I conducted research for the past three years is artificial intelligence applied in electrical engineering. A lot of my research will be conducted into this area. Specifically I will address applications of artificial neural networks and fuzzy logic systems in electrical engineering, as well as in other fields.

I propose to address research topics that will allow me to implement intelligent systems by using the microcontrollers. I considered this area because there are two postgraduate programs in Electrical Engineering: Computer Techniques in Electrical Engineering or Advanced Systems for Industrial use Electricity at the Faculty of Engineering of Hunedoara. I plan to approach research topics in the field above and include students from these study programs into this research; the results of this endeavor could be published either in the Scientific Student Communication Session, or in other journals or conferences. Thus, I will try to guide at least 3 postgraduate students / year in their participation in the scientific student sessions which usually takes place in May of each year. Also, after obtaining the habilitation certificate, I will address such topics with PhD fellows.

In the future I propose the following minimum quantity indicators:

- 2 articles / year in journals indexed ISI or ISI Proceedings
- 2 articles / year in journal or conference indexed BDI

I also intend to participate in grant / research project contest where the competition is open.

I will participate in organizing conferences that will be held at the Faculty of Engineering of Hunedoara, or in which the Faculty of Engineering of Hunedoara is co-organizer.

I will continue being a reviewer to the ISI / BDI journals at which I worked so far. I will also respond to other requests of conferences or journals to participate as a reviewer and / or member of the International Committee of the program.

Along with my fellow department / faculty colleagues, I will attempt to establish a research center. Through this research center, I and my colleagues will try to raise funds by participating in research project competitions within our field of expertise. In order to raise funds, I will also seek to get involved with businesses for obtaining research contracts. Such research contracts may have a double positive impact: on the one hand, for the teaching staff, by obtaining funds to attend international conferences, and on the other hand, by attracting students into research teams in order to increase their competitiveness on the labor market.

C. OTHER ACTIVITIES IN THE DEPARTMENT / FACULTY

As part of the teaching staff, I dealt with all types of activities: teaching, research, collaboration with other universities or firms and organizational activities. I intend to continue these activities in the future.

As President and member of the Curricula and Syllabi Chair within the Council of Faculty of Engineering Hunedoara, I plan to participate in monitoring the course sheets and the curricula of the study programs held at the Faculty of Engineering of Hunedoara: the annual update of subject sheets and their posting on the faculty website, the annual curricula updating and their posting on the faculty website.

As President of the teaching staff and the human resources committee of the Council of the Department of Electrical Engineering and Industrial Informatics, I will actively participate in activities that take place within the department, activities in which lay the powers of these committees: drafting the payrolls, monitoring the teaching process, peer evaluation of teachers, assessment of entry files and files for participation in merit or gradation competitions etc.

Being in charge of the study programs, I will monitor the teaching process of the respective study programs through the following actions:

- Adapting the curricula to labor market requirements; I believe that this action is among the most important actions to increase the percentage of graduates employed in the field they have studied
- Update curricula to the requirements imposed by ARACIS, as well as standards and requirements imposed by UPT regulations.
- Coordinating the preparation of dossiers for authorization / accreditation / periodic evaluation for these study programs.
- Monitoring graduates in order to follow the way in which they integrate into the labor market.

Also, in order to increase the quality of the training the students undertake, I will attempt to get involved in a series of measures to make graduates more competitive in the labor market. In this regard, alongside with other teachers, I will try to initiate collaboration between the Faculty and businesses in the area to engage students, especially of the ones in senior year or in the postgraduate study programs, in order to solve real-life problems faced by the economic agents. These collaborations aim will provide continuous education and training of a quality consistent level with the needs of the economic environment. As far as the existence of project competition for human resources development goes, I will try to attract funds for this activity which I consider particularly important for a graduate. I believe that by applying such actions, some weaknesses existing in higher education can be repaired, such as the limited ability of universities to provide practical education and training in line with labor market needs, low productivity of businesses due to non-application of new and innovative methods in their field (weak connection between universities and the economic environment).

September 2015 Prof. Dr. Eng. Manuela PĂNOIU

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