გიორგი ჭყონია

# ძალური ტრანსფორმატორების დიაგნოსტიკის თანამედროვე მეთოდები და საშუალებები

წარდგენილია დოქტორის აკადემიური ხარისხის
მოსაპოვებლად

საქართველოს ტექნიკური უნივერსიტეტი
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საქართველოს ტექნიკური უნივერსიტეტი

ენერგეტიკისა და ტელეკომუნიკაციის ფაკულტეტი

ჩვენ, ქვემორე ხელისმომწერნი ვადასტურებთ, რომ გავეცანით ჭყონია გიორგის მიერ შესრულებულ სადისერტაციო ნაშრომს დასახელებით: „ძალური ტრანსფორმატორების დიაგნოსტიკის თანამედროვე მეთოდები და საშუალებები“ და ვაძლევთ რეკომენდაციას საქარველოს ტექნიკური უნივერსიტეტის ენერგეტიკისა და ტელეკომუნიკაციის ფაკულტეტის სადისერტაციო საბჭოში მის განხილვას დოქტორის აკადემიური ხარისხის მოსაპოვებლად.

თარიღი

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ინდივიდუალური პიროვნებების ან ინსტიტუტების მიერ ზემომოყვანილი დასახელების დისერტაციის გაცნობის მიზნით მოთხოვნის შემთხვევაში მისი არაკომერციული მიზნებით კოპირებისა და გავრცელების უფლება მინიჭებული აქვს საქართველოს ტექნიკურ უნივერსიტეტს.

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ავტორის ხელმოწერა

ავტორი ინარჩუნებს დანარჩენ საგამომცემლო უფლებებს და არც მთლიანი ნაშრომის და არც მისი ცალკეული კომპონენტების გადაბეჭდვა ან სხვა რაიმე მეთოდით რეპროდუქცია დაუშვებელია ავტორის წერილობითი ნებართვის გარეშე.

ავტორი ირწმუნება, რომ ნაშრომში გამოყენებული საავტორო უფლებებით დაცული მასალებზე მიღებულია შესაბამისი ნებართვა (გარდა იმ მცირე ზომის ციტატებისა, რომლებიც მოითხოვენ მხოლოდ სპეციფიურ მიმართებას ლიტერატურის ციტირებაში, როგორც ეს მიღებულია სამეცნიერო ნაშრომების შესრულებისას) და ყველა მათგანზე იღებს პასუხისმგებლობას.

# რეზიუმე


ukanasknel aTwleulebSi samrewvelo warmoebis vardnam mogviyvana gacveTili eleqtrodanadgarebis raodenobis mkveTr zrdasTan. eleqtromowyobilobis muSaobis saSualo xangrZlivobam gadaaWarba 40 wels da maTma 80 % -ma gamoimuSava Tavisi fizikuri resursi. SeiniSneba teqnologiuri darRvevebisa da avariebis raodenobis zrdis myari tendencia, romelTa umetesoba modis zeTiT avsebul mowyobilobebze, pirvel rigSi Zalovan transformatorebze avtotransformatorebsa da reaqtorebze.

Zaluri transformatori warmoadgens nebismieri qvesadguris yvelaze ufro ZviradRirebul elements, romelTa umetesoba mravali wlis ganmavlobaSi muSaobs sxvadasxva klimatur pirobebSi da ganicdis eleqtromagnituri da meqanikuri bunebis Sinagad da garegan zemoqmedebas. amitom transformatorebis eqspluataciis dros gamoricxuli ar aris aRiZras sxvadasxva saxis defeqtebi, romlebic sxvadasxva xarisxiT aisaxeba maT muSaobaze.

dReisaTvis saqarTvelos elmomaragebis sistemaSi Zaluri trans-formatorebis mniSvnelovanma nawilma amowura Tavisi muSaobis resursi. Qqveynis ekonomiuri situacia, agreTve transformatorebis saerTo raodenobis didi ricxvi ar iZleva uaxloes xanSi maTi Secvlis saSualebas. Aamitom transformatorebis drouli diagnostika metad aqtualuri Temaa.

sazRvargareT Catarebulma statistikurma gamokvlevebma aCvena, rom Zaluri transformatoris mtyunebis albaToba weliwadSi Seadgens 0,0062. sxva sityvebiT rom vTqvaT, es niSnavs, rom 160 zeTiani transformatoris mqone energosistemaSi ukidures SemTxvevaSi SesaZlebelia erTi avaria weliwadSi.

amJamad Zaluri transformatorebisa da avtotransformatorebis saeqspluatacio maxasiaTeblebis gansazRvrisa da sistemebis defeqtebis ganviTarebis donis mdgomareobis Sefasebisatvis, sul ufro farTod mimarTaven kompleqsur diagnostikur gamokvlevas. aseTi gamokvlevebi saSualebas gvaZleven ara marto gamovavlinoT ganviTarebadi defeqtebi, SevafasoT maTi saSiSroebis done, aramed davasabuToT kapitaluri remontis saWiroeba, moculoba da vadebi.

principul problemas warmoadgens koncefciis Teoriuli uzrunvelyofis arsebiTi CamorCena diagnostikis Tanamedrove saSualebebisa da informaciuli teqnologiebis miRwevebis realuri SesaZleblobebisagan.

ukanasknel ori aTwleulis ganmavlobaSi msoflio masStabiT ganuwyvetliv muSavdeba da praqtikaSi inergeba qvesadgurebisa da transformatorebis diagnostikuri meTodebi da xelsawyoebi, romlebic damzadebulia Tanamedrove mikroeleqtronikis bazaze, romlebic advilad uRldebian personalur kompiuterebTan.

teqnikurad dasabuTebuli diagnozis dasma SesaZlebelia mxolod srulyofili informaciis pirobebis statistikuri mona-

cemebis Sekrebis, gare daTvalierebisa da specialuri xelsawyoebis saSualebiT Catarebuli eqsperimentuli gamokvlevebis Sedegad.

amitom udaod aqtualuri xdeba kontrolis iseTi axali meTodebis damuSaveba, romlebiTac transformatoris gaxsnis gareSe moxdeba misTvis damaxasiaTebeli sxvadasxva parametrisa da monacemis gazomva, defeqtebis aRmoCena da aRmofxvra.

naSromis I Tavi eZRvneba literaturul mimoxilvas, sadac moyva-nilia transformatoris mokle istoria da Zaluri transformatorebis daniSnuleba, ZiriTadi elementebi da muSaobis principi. transformatorebis nominaluri monacemebi da teqnikuri maxasiaTeblebi. maTi dazianebis ZiriTadi saxeebi. Zalovani transformatorebis kontrolis ZiriTadi meTodebi. Eeleqtruli da qimiuri gamocdebis aucilebeli da damatebiTi CamonaTvlebi; transformatoris diagnostikis xerxebi.

naSromis II TavSi ganxilulia MmaRali Zabvis eleqtromowyobilobebis diagnostikis sistemis meTodologia. rogorc cnobilia maRali Zabvis mowyobilobebi eqvemdebarebian defeqtebisa da uwesivrobebis Camoyalibebis maRal risks da aqvT sakmaod maRali avariuli SemTxvevebi. dReisaTvis gamoyenebuli uwesivrobis gamovlenisa da profilaqtikis meTodebi saSualebas iZlevian mxolod ramdenadme SevamciroT mtyunebebi.

am TavSi warmodgenilia saqarTvelos saxelmwifo eleqtrosistemaSi 110-500 kv Zabvis 1500 erTeuli mowyobilobis saxeobebis mixedviT mtyunebebis, uwesivrobisa da defeqtebis gamovlenis jamuri ganawileba qvesadgurebSi, Ria da daxurul gamanawilebel mowyobilobebSi eqspluataciis sami wlis Sedegebis mixedviT.

mocemulia diagnostikis sistemis samdoniani struqturuli sqema,sadac moyvanilia diagnostikuri parametrebis ricxvi da saxeebi. diagnostikuri parametrebis gansazRvraSi mniSvnelovan moments warmoadgens maTi registraciis perioduloba, romelic damokidebulia obieqtis nebismier sakontrolo kvanZsa da detalSi defeqtebis warmoqmnisa da ganviTarebis siCqareze.

amave TavSi mocemulia diagnostirebis algoriTmi, romlis ZiriTad nawils warmoadgens modeli. modeli Sedgeba mTeli rigi nawilebisagan (blokebisagan), romelTac erTmaneTTan gaaCniaT funqcionaluri kavSirebi. rogorc wesi aseTi nawilebi erTmaneTisagan izolirebulad ar ganixilebian. maTi jamuri wvlili mTlianad modelis funqcionirebaSi ganpirobebulia nawilebs Soris urTierTqmedebiT. mowyobilobis diagnostirebisas mniSvnelovania vicodeT movlenaTa Tanmimdevroba, romelTac SeuZliaT migviyvanon detalebisa da kvanZebis mtyunebamde.

naSromis mesame TavSi ganxilulia Zaluri transformatorebis maTematikuri modelebi.

maTematikuri modelireba warmoadgens adamianis mier gare samyaros movlenebis Secnobis erT-erT ZiriTad instruments. igi aris realuri obieqtis, procesis an sistemis Seswavlis saSualeba maTi maTematikuri modeliT Secvlis gziT, romelic ufro mosaxerxebelia gamomTvleli manqanis gamoyenebiT eqsperi-

mentuli kvlevebis Catarebisas. maTematikuri modelirebis qveS igulisxmeba Sesaswavli movlenis ZiriTadi kanonzo-mierebani da kavSirebi. es SeiZleba iyos formulebi an gantolebebi, wesebis an SeTanxmebebis krebuli gamosaxuli maTematikuri formiT.

maTematikuri modelireba samecniero-teqnikuri progresis ganuyofeli nawilia. Ees aris meTodologia, romelic ar cvlis samecniero disciplinebs, ar uwevs maT konkurencias, magram monawileobs yvela sferoSi mimdinare SemoqmedebiT kvlevebSi.

maTematikuri modelirebis farTo gamoyeneba saSualebas iZleva aiwios Teoriuli gamokvlevebis saerTo done, Catardes isini eqsperimentalur gamokvlevebTan mWidro kavSirSi.

eleqtrodanadgarebis maTematikuri modelebis Seqmna da Seswavla iZleva eleqtrodanadgarebis kvlevis did perspeqtivebs. Deleqtromowyobilobata diagnostikis sferoSi mimdinare samecniero - kvleviT samuSaoebSi kompiuteris farTod gamoyenebam aucilebeli gaxada maTematikur modelirebasTan erTad eleqtruli wredebis Teoriis sferoSi axali Teoriuli midgomebis damuSaveba da miRebuli Sedegebis WeSmaritebis Sefaseba.

dReisaTvis aqtualurad iTvleba induqciurad dakavSirebuli wredebis modelirebis amocana. aseTi saxis wredebSi mimdinare fizikuri procesebis Sesabamisi maTematikuri modelebis Sesadgenad saWiro gaxda axali aTvlis sistemis SemoReba. adekvaturi modelirebis amocana didi xania aRelvebs swavlul eleqtroteqnikosebs, razec metyvelebs eleqtroteqnikosTa saerTaSoriso komisiis kongresze gamarTuli diskusiebi. Zaluri transformatori induqciurad dakavSirebuli wredis klasikuri magaliTia. Aamitom naSromSi Sedgenilia erTfaza da samfaza transformatorebis iseTi maTematikuri modelebi, romlebic srulad asaxaven maTSi mimdinare fizikur procesebs.

datvirTvis reJimSi samfaza transformatoris Sesabamisi gantolebaTa sistemis amosaxsnelad Sedgenili iqna blok-sqema, xolo mis safuZvelze - pirveladi da meoreuli denebis gamosaangariSebeli programa.

naSromis meoTxe TavSi moyvanilia Cems mier damuSavebuli Zalur transformatorSi ganviTarebadi defeqtebis gansazRvris algoriTmi, romelic saSualebas iZleva qromatografiuli analizis monacemebis mixedviTa da specialuri diagnostikuri cxrilebis gamoyenebiT gansazRvruli iqnes defeqtis ganviTareba.

amave TavSi moyvanilia Tbovizoruli diagnostikis dros mdgomareobis SefasebisaTvis gasaTvaliswinebeli faqtorebis CamonaTvali da maTi daxasaTeba, romlebic gavlenas axdenen infrawitel kontrolze.

Zaluri transformatoris gragnilebSi xviaTaSorisi mokled SerTvis Sedegad gamowveuli gragnilebis deformaciis mimarT yvelaze ufro mgrZnobiarea induqciurobis parametri. aseTi transformatorebis gragnilebSi sawyisi deformaciebis aRZvrisas da xviaTaSorisi mokled SerTvis SemTxvevaSi periodidan periodamde xdeba induqciurobis ganviTarebadi gazrda an Semcireba, romelsac Tan axlavs sakontrolo transformatoris

gragnilebis Seuqcevadi rRveva. Mam MmeTodis bazaze Seqmnilia Zaluri transformatorebis parametrebis kontrolis sainformacio - sazomi sistema, romelic SeiZleba gamoyenebuli iqnes mokled SerTvis cdebisa da eqspluataciis dros qselidan gamourTvelad Zaluri transformatorebis gragnilebis mdgomareobis operatiuli kontrolisaTvis. sainformacio-sazomi sistema saWiroa gamoyenebuli iqnes im reJimebisagan swrafmoqmed dacvasTan kavSirSi, romelnic aRiZvrebian Zalovan transformatorebis gragnilebSi mokled SerTvis gamo maTSi eleqtrodinamiuri Zalvebisagan dazianebebisa da narCeni deformaciis Sedegad parametrebis cvlilebiT.

# Abstract

In the result of industrial production fall during last decades the number of worn-out electrical facilities have abruptly increased. Average duration of working capacity of electrical facilities exceeded 40 years and 80% of them generated their physical resources. A strong tendency of technologic disturbances and accidents is noticed, mostly on facilities filled with oil, first of all in power transformers, autotransformers and reactors.

A power transformer represents the most expensive part of any substation most of which work the year round in various climate conditions and undergo internal and external influence of electromagnetic and mechanic nature. That is why, during exploitation of transformers various defects can emerge which are expressed at work in different ways.

Nowadays in the system of electric supply a significant part of power transformers exhausted their resources. Economical condition of the country and great number of transformers' total quantity do not allow to change them. Thus, timely diagnostics of transformers is quite urgent.

Statistical studies, carried out abroad, showed that probability of transformers abort is 0.0062 in a year. Saying in other words this means that in energetic system with 160 oil transformers one accident in a year is possible in extreme case.

At present for estimation of the state of system defects development and determination of exploitation properties of power transformers and autotransformers, complex diagnostic study is widely used. This kind of studies allow to reveal either developing defects, estimate a level of danger, or necessity of major repair, capacity and terms.

Basic problem is a fundamental lagging of theoretical provision of conception of modern facilities and real possibilities of information technology progress.

During last two decades diagnostic methods of transformers, substations and devices are implanted in practice and continually processed worldwide. They are made on the base of modern microelectronics easily interrelated with personal computers.

Making technically confirmed diagnosis is possible only after gathering statistical data of complete informational terms, external inspection and experimental studies carried out by means of special devices.

Thus working out new methods of control is becoming very urgent. By these methods measuring various parameters and data of transformer, revealing defects and their correction will be possible without opening facility.

The first chapter of the work is devoted to the literature review where a short history of transformers, dedication of power transformers and an operation concept, nominal data and technical properties of transformers, main types of their damage, basic methods of power transformer control, main and additional lists of chemical and electrical tests, ways of transformer diagnosis are given.

In the second chapter of the work methodology of diagnostic system of high potential electrical equipment is discussed. It is commonly known that high potential electrical equipment is under the high risk of forming defects and malfunctions and they have too much accidents. Currently, methods used for prophylaxis and revealing malfunctions allow to decrease aborts somehow.

According 1500 units of devices of 110-500 kW voltage in the state electrical system of Georgia, total distribution of revealing aborts, malfunctions and defects

through substations, open and closed allocating arrangements, subsequent to the results of three year exploitation, are given in this chapter.

Three-level structural scheme of diagnostic system with numbers and types of diagnostic parameters is given. In specification of diagnostic parameters periodicity of their registration is important. It depends on defect formation in parts or any control knot of the object and development speed.

In the same chapter diagnostic algorithm is given, the main part of which is a model. The model consists of various parts (blocks) which are related to each other functionally. As a rule such parts are not reviewed separately. Their total bit in the model functioning is conditioned by interaction between the parts. When making diagnosis knowing sequence of events is important. These events may cause an abort of details and knots.

In the third chapter of the work mathematical models of power transformers are discussed.

Mathematical modeling is one of the main instruments for getting to know events of external world by human. It represents a mean for learning a real object, process or system via replacing them with mathematical model. It is more convinient when experimental studies are carried out using calculation machines. Mathematical modeling means basic connections and relationships of learnt event. This can be formulas or equations, collection of rules and coordination in mathematical representation.

Mathematical modeling is an integral part of scientific-technical progress. This methodology does not change scientific disciplines, does not compete them but participates in all fields of current creative studies.

Wide use of mathematical modeling allows rising general level of theoretical studies and to carry out them in close relation with experimental researches.

Making and learning mathematical model of electrical facilities give great perspective for studying electrical facilities. Wide use of computers in scientific works passing in the field of electrical facility diagnostics made it necessary to process new theoretical approaches in the field of electrical circuit theory and estimate validity of the results.

Nowadays modeling problem of inductively connected circuits is quite urgent. To make mathematical model corresponding physical processes in such circuits it is necessary to introduce a new counting system. Electric technologists have been conscious about adequate modeling problem for a long time. This is seen in discussions at the congress of international commission of electric technologists. Power transformer is a classical sample of inductively connected circuit. That is why, in the work there is a mathematical model of single-phase and tree-phase transformers which completely expresses physical processes taking place in them.

At download mode for solution of equation systems corresponding to three-phase transformers, block chart was made and basing on it – program calculating primary and secondary currents.

For solving equation system corresponding to three-phase transformer in the mode of load, a block diagram was made and basing on it – a program for calculation of primary and secondary currencies was created.

In the fourth chapter an algorithm (worked out by me) for specification of developing defects in power transformers is represented. This allows to determine development of defects using special diagnostic tables, according data of chromatographic analysis.

In the same chapter the list of factors to be considered for estimation of condition during infrared diagnostics and characterization of these factors are given. They influence infrared control.

Induction parameters are the most sensitive to windings deformation caused by turn-to-turn faults of power transformers windings. In the windings of such transformers, at forming initial deformities and in case of turn-to-turn faults, developing increase or decrease of inductivity from period to period accompanied by irreversible destruction of controlling transformer windings. Basing on this method informational-measuring control system of power transformer parameters are made. It can be used at short circuit tests and exploitation without switching off from the system for operating control of power transformers' winding conditions. Informational-measuring system have to be used in conjunction with fast-acting protection from the modes arising in windings of the power transformers due to short circuits with changing parameters in the result of damages due to electrodynamic forces and residual deformations.

# შინაარსი

# ცხრილების ნუსხა

# ნახაზების ნუსხა

# შესავალი

**samuSaos aqtualoba.** Uukanaskneli aTwleulebi xasiaTdeba eleqtruli sadgurebisa da qselebis teqnikur gadaiaraRebaSi investiciebis dabali doniT. samrewvelo warmoebis vardnam mogviyvana gacveTili eleqtrodanadgarebis raodenobis mkveTr zrdasTan. eleqtromowyobilobis muSaobis saSualo xangrZlivobam gadaaWarba 40 wels da maTma 80 % -ma gamoimuSava Tavisi fizikuri resursi. SeiniSneba teqnologiuri darRvevebisa da avariebis raodenobis zrdis myari tendencia, romelTa umetesoba modis zeTiT avsebul mowyobilobebze, pirvel rigSi Zalovan transformatorebze avtotransformatorebsa da reaqtorebze.

Zaluri transformatori warmoadgens nebismieri qvesadguris yvelaze ufro ZviradRirebul elements. ganasxvaveben saerTo da specialuri daniSnulebis Zalovan transformatorebs. saerTo daniSnulebis Zalovani transformatorebi gamoiyeneba iseTi qselebisa da momxmareblebis kvebisaTvis, romlebic ar xasiaTdebian muSaobis gansakuTrebuli pirobebiT, datvirTvis xasiaTiTa da muSaobis reJimebiT. specialuri daniSnulebis Zalovani transformatorebi gamoiyeneba iseTi qselebisa da momxmareblebis kvebisaTvis romlebic xasiaTdebian muSaobis gansakuTrebuli pirobebiT, datvirTvis xasiaTiTa da muSaobis reJimebiT. aseTi qselebisa da momxmareblebis ricxvs miekuTvnebian miwisqveSa maRarosa da Saxtis qselebi da danadgarebi, gammarTveli mowyobilobebi. Eeleqtruli Rumelebi da sxva.

transformatorebis umetesoba mravali wlis ganmavlobaSi muSaobs sxvadasxva klimatur pirobebSi da ganicdis eleqtromagnituri da meqanikuri bunebis Sinagad da garegan zemoqmedebas. amitom transformatorebis eqspluataciis dros gamoricxuli ar aris aRiZras sxvadasxva saxis defeqtebi, romlebic sxvadasxva xarisxiT aisaxeba maT muSaobaze. erTi saxis defeqtebiT transformatori SeiZleba xangrZlivad darCes muSaobaSi, xolo sxva saxis defeqtebiT saWiroa maTi dauyonebliv muSaobidan gamo-

yvana. TiToeul SemTxvevaSi muSaobis Semdgomi gagrZelebis SesaZlebloba ganisazRvreba dazianebis xasiaTiT. Ppersonalis araoperatiulobisa da umniSvnelo defeqtebis gamosworebisaTvis zomebis udroo miRebas mivyavarT transformatorebis avariul gamorTvamde.

dReisaTvis saqarTvelos elmomaragebis sistemaSi Zaluri transformatorebis mniSvnelovanma nawilma amowura Tavisi muSaobis resursi. Qqveynis ekonomiuri situacia, agreTve transformatorebis saerTo raodenobis didi ricxvi ar iZleva uaxloes xanSi maTi Secvlis saSualebas.Aamitom transformatorebis eqspluataciis saimedobis SesanarCuneblad mniSvnelovani roli ekisreba maT diagnostikur kontrols.

msoflio gamocdileba gviCvenebs, rom mZlavri transformatorebis SemTxveviTi avariiT miyenebuli ekonomiuri zarali, romelic dakavSirebulia mxolod Zabvis Sewyvetis gamo samrewvelo sawarmoebis gaCerebasTan milionobiT dolarebiT. ukve ar vlaparakobT im udides danaxarjebze, romelic saWiroa am ZviradRirebuli mowyobilobis muSaunarianobis aRsadgenad. amitom transformatorebis drouli diagnostika metad aqtualuri Temaa [1].

sazRvargareT Catarebulma statistikurma gamokvlevebma [2] aCvena, rom Zaluri transformatoris mtyunebis albaToba weliwadSi Seadgens 0,0062. sxva sityvebiT rom vTqvaT, es niSnavs, rom 160 zeTiani transformatoris mqone energosistemaSi ukidures SemTxvevaSi SesaZlebelia erTi avaria weliwadSi. meore mxriv, Tanamedrove eleq-troenergetikis damaxasiaTebeli tendenciaa ZiriTadi Zaluri mowyobilobebis cveTis xarisxis zrda da arasakmarisi ganaxlebis tempebi.Ddazianebis mizezebi dakavSirebulia eqspluataciis cud pirobebTan, uxarisxo remontsa da montaJTan. mniSvnelovan rols TamaSobs transformatoris konstruqciis calkeuli elementebis faruli defeqtebi da arasakmarisi xarisxis saizolacio masalebi.

energetikul bazasa da eleqtroenergiis uwyvet moTxovnas Soris mdgomareobis obieqturi winaaRmdegoba Tavis asaxvas pou-

lobs am problemis gadasawyvetad samecniero-teqnikuri gzebis Ziebis intensifikaciaSi. ganviTarebis adreul stadiaSi eleqtromowyobilobebis muSaobaSi defeqtebis gamovlena, avariuli situaciebis aRZvramde maTi likvidaciisaTvis drouli gadawyvetilebis miReba, Seamcirebs da ara marto Tavidan agvacilebs mniSvnelovan zarals, aramed Seamcirebs gacdenebsa da remontis xarjebs, gaaxangrZlivebs misi muSaobis vadas. eleqtromowyobilobis racionaluri, usafrTxo da efeqturi eqspluataciisaTvis da remontze gadayvanisaTvis diagnostikis arsebuli sistemebi unda Seivsos mTeli rigi specialuri meTodebiTa da teqnologiebiT, romelTac gaaCniaT unari muSa reJimSi awarmoon konkretuli elmowyobilobis mimdinare mdgomareobis statistika.

amJamad Zaluri transformatorebisa da avtotransformatorebis saeqspluatacio maxasiaTeblebis gansazRvrisa da sistemebis defeqtebis ganviTarebis donis mdgomareobis Sefasebisa Tvis, sul ufro farTod mimarTaven kompleqsur diagnostikur gamokvlevas. aseTi gamokvlevebi saSualebas gvaZleven ara marto gamovavlinoT ganviTarebadi defeqtebi, SevafasoT maTi saSiSroebis done, aramed davasabuToT kapitaluri remontis saWiroeba, moculoba da vadebi [3].

teqnikuri mdgomareobis arsebuli meTodebi da saSualebebi mowyobilobis kompleqsuri gamokvlevebis dros iZlevian defeqtebis umravlesobis SemCnevis saSualebas. magram kompleqsuri gamokvlevebi maTi didi Sromatevadobisa da Rirebulebis gamo sruldeba mxolod strategiul eleqtromowyobilobebze remontze gadayvanis dros da bunebrivia ver uzrunvelyofs ganviTarebadi defeqtebis droul SemCnevas.

principul problemas warmoadgens koncefciis Teoriuli uzrunvelyofis arsebiTi CamorCena diagnostikis Tanamedrove saSualebebisa da informaciuli teqnologiebis miRwevebis realuri SesaZleblobebisagan.

ukanaskneli ori aTwleulis ganmavlobaSi msoflio masStabiT ganuwyvetliv muSavdeba da praqtikaSi inergeba qvesad-

gurebisa da transformatorebis diagnostikuri meTodebi da xelsawyoebi, romlebic damzadebulia Tanamedrove mikroeleqtronikis bazaze. maT safuZvelze gamoCnda Tanamedrove vibrodiagnostikis, Tbovizoruli kontrolis, zeTis qromatografiuli analizis, oscilografebisa da registratorebis mravali saxesxvaobebi, romlebic advilad uRldebian personalur kompiuterebTan [4].

amasTanave diagnostikis Tanamedrove meTodebi da teqnikuri saSualebebi energosistemebSi saSualebas ar iZlevian Zviradrirebuli eleqtromomowyobilobis gaxsnis gareSe gamovlenili iqnas calkeuli elementebis muSaobis reJimebi. amasTan dakavSirebiT iweleba eletromowyobilobis remontSi gadayvanis dro, ixarjeba operatiuloba da izrdeba avariuli reJimebis gazrdis albaToba.

teqnikurad dasabuTebuli diagnozis dasma SesaZlebelia mxolod srulyofili informaciis pirobebis statistikuri monacemebis Sekrebis, gare daTvalierebisa da specialuri xelsawyoebis saSualebiT Catarebuli eqsperimentuli gamokvlevebis Sedegad.

amitom udaod aqtualuri xdeba kontrolis iseTi axali meTodebis damuSaveba, romlebiTac transformatoris gaxsnis gareSe moxdeba misTvis damaxasiaTebeli sxvadasxva parametrisa da monacemis gazomva, defeqtebis aRmoCena da SesaZlo avariebis prognozirebis mizniT damuSavdeba miRebuli Sedegebi,

**samuSaos mizania** Zaluri transformatoris iseTi monitoringisa da diagnostikuri saSualebis damuSaveba, romelic muSa Zabvis qveS uzrunvelyofs ganviTarebadi defeqtebis adreul aRmoCenas.

**ZiriTadi amocanebi:**

1. saqarTvelos saxelmwifo eleqtrosistemaSi 110-500 kv Zabvis qvesadgurebis, Ria da daxuruli gamanawilebeli mowyobilobebis saxeobebis mixedviT warmodgenili mtyunebebis, uwesivrobisa da defeqtebis mdgomareobis dadgena;

2. Zaluri transformatoris diagnostikis stuqturuli sqemis algoriTmis daxvewa;
3. Zalur transformatorebSi mimdinare fizikuri procesebis Sesabamisi maTematikuri modelis damuSaveba.
4. kontrolis iseTi axali meTodis damuSaveba, romlebiTac transformatoris gaxsnis gareSe uwyvetad moxdeba misTvis damaxasiaTebeli induqciurobis parametris mudmivi kontroli da misi cvlilebs safuZvelze swrafmoqmed dacvasTan kavSiriT dazianebuli transformatoris amorTva.
5. Zaluri transformatorebis monitoringis daxvewis teqnologiaSi mikroprocesoruli teqnikis gamoyenebis Sesaxeb rekomendaciis gacema.

**kvlevis meTodebi.** sadisertacio samuSaos Sesrulebisas gamoyenebuli iqna Teoriuli da empiriuli SemecnebiTi meTodebi. Teoriul doneze es meTodebia eleqtruli wredebisa da gazomvebis Teoria. Eempiriul doneze gamoyenebuli iqna fizikuri da maTematikuri modelirebis meTodebi, maT ricxvSi Catarebuli iqna kvlevebi sanimuSo maketze.

**samecniero siaxle.**

1. Sedgenili iqna Zaluri transformatorebis diagnostikis struqturuli sqema, romelic Sedgeba: parametrebis gardaqmnisa da analizis, teqnikuri mdgomareobis, dinamiuri maxasiaTeblebisa da ganviTarebadi defeqtebisa da narCeni resursebis modelebis blokebisagan;

2.damuSavebuli iqna Zalur transformatorebSi mimdinare fizikuri procesebis Sesabamisi maTematikuri modeli uqmi svlisa da datvirTvis reJimSi;

3. Zaluri transformatorebis parametrebis kontrolis sainformacio - sazomi sistemis safuZvelze damuSavebuli iqna kompiuteruli programa transformatoris gragnilebis induqciuri winaRobis kontroliT dazianebis gansazRvrisaTvis, romelsac SeuZlia imuSaos swrafmoqmed dacvasTan kavSirSi.

**praqtikuli Rirebuleba.**

1. warmodgenili meTodika saSualebas iZleva operatiulad ganvsazRvroT muSa Zabvis qveS Zaluri transformatorebis mimdinare mdgomareoba, rac Tavidan agvacilebs avariul situaciebsa Sesabamisad, did ekonomiur zarals.

2. Zalur transformatorebSi mimdinare fizikuri procesebis Sesabamis, daxvewil maTematikuri models didi mniSvneloba aqvs transformatoris optimaluri eleqtruli da magnituri parametrebis dadgenis saqmeSi, rac saSualebas mogvcems damzaddes Semcirebuli masalatevadobis Zaluri transformatorebi.

sadisertacio samuSaos ZiriTadi Sedegebi moxsenebuli iqna stu-s studentTa Ria 79-e saerTaSoriso samecniero konferencias (2011 weli); **publikaciebi.** sadisertacio samuSaoebis Sedegebi gamoqveynebuli iqna sam samecniero statiaSi.

**Ddisertaciis struqtura da mocouloba.** Ddisertacia Sedgeba Sesavalisa da oTxi Tavisagan, romlebic gadmocemulia 116 gverdze. Seicavs 55 naxazs, 23 cxrils, 1 danarTsa da 96 dasaxelebis literaturas.

# 1. ლიტერატურის მიმოხილვა

## Tavi I. literaturuli mimoxilva

### 1.1. transformatoris mokle istoria da Zaluri transformatorebis ZiriTadi elementebi da muSaobis principi.

movlena, romelic safuZvlad daedo eleqtruli transformatoris moqmedebas aRmoCenili iqna 1831 wels ingliseli fizikosis maikl faradeis mier eleqtrobis dargSi kvlevebis Catarebis dros. Aam kanonis aRmoCenidan 45 wlis Semdeg rusi pavle iabloCkovis mier dapatentebuli iqna pirveli transformatori gaxsnili gulariT, xolo 1884 wels ingliseli Zmebis joni da eduard gopkinsonebis mier Seqmnili iqna Caketil gulariani transformatori romelic Seicavda Tanamedrove transformatorebis TiTqmis yvela ZiriTad elements.

Tanamedrove Zaluri transformatori warmoadgens rTul mowyobilobas, romelic Sesdgeba sxvadasxva saxis konstruqciuli elementebis didi raodenobisagan, romlebic ama Tu im saxiT gavlenas axdenen mis muSaobaze.

Zaluri transformatoris daniSnulebaa rogorc eleqtroenergiis gardaqmna eleqtrul qselebsa da danadgarebSi, aseve eleqtroenergiis miReba da gamoyeneba.Aarsebobs erTfaza, orfaza, samfaza Zaluri transformatorebi Dda avtotransformatorebi.

nax.1.1-ze mocemulia erTfaza (a) da samfaza (b) transformatorebis magnituri nakadebi.

Tanamedrove transformatorebi mcired gansxvavdebian XIX saukunis dasawyisis transformatorebisagan. isini iseve Sedgebian izolirebuli firfitebisagan da spilenZis gamtarebisagan damzadebuli gragnilebisagan. Tanamedrove transformatorebi Tavis winamor-bedebs simZlavris mixedviT 500-jer aRematebian maTi simZlavre aRwevs 1 mln kvt-ze mets, xolo Zabvis mixedviT 15-jer aRematebian da SeuZliaT imuSaon 1150 kv Zabvis dros. eqspluataciis xangrZlivoba meryeobs 25 dan 50 wlamde; maTi masa

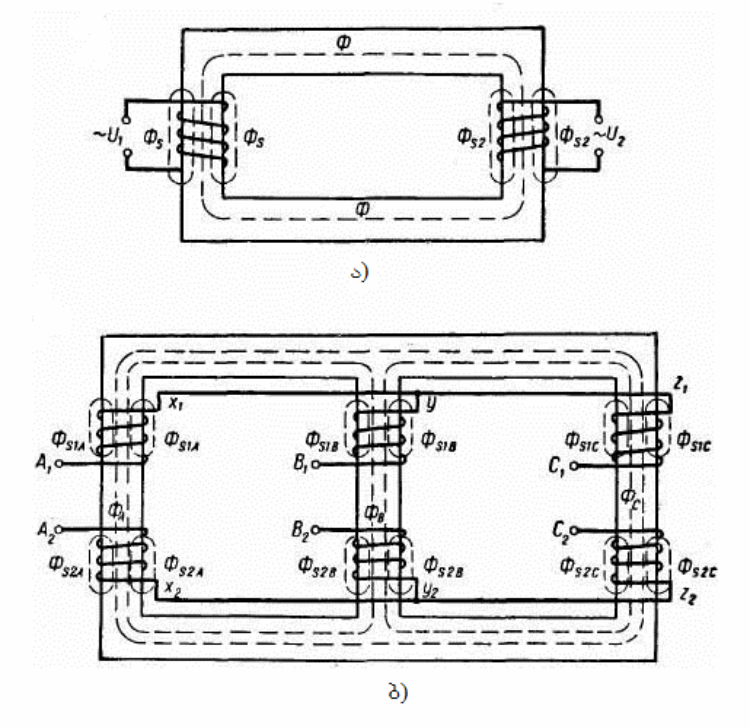
erTeulovan simZlavreze gaangariSebiT Semcirda daaxloebiT 10-jer, xolo margi qmedebis koeficientma gadaaWarba 99 %-s [1].

Mmokled ganvixiloT Zaluri transformatoris muSaobis principi. transformatorSi gamtarisagan daxveul gragnils, romelic mierTebulia kvebis wyarosTan da qmnis magnitur vels, pirveladi ewodeba. Mmeore gragnils, romelSic am velis moqmedebiT aRiZvreba eleqtromamoZravebeli Zala (emZ) da mierTebulia eleqtroenergiis momxmarebelTan, ewodeba meoreuli.

transformatoris muSaoba dafuZnebulia or bazisur principze:

1. droSi cvalebadi eleqtruli deni qmnis droSi cvalebad magnitur vels (eleqtromagnetizmi);

2. magnituri nakadis cvlileba gragnilSi iwvevs eleqt-romamoZravebeli Zalis (emZ) aRZvras (eleqtromagnituri induqcia




nax.1.1. erTfaza (a) da samfaza (b) transformatorebis magnituri nakadebi.

Tu pirvelad gragnils CavrTavT cvladi denis wredSi (nax.1.1.a), maSin masSi gaivlis cvladi deni da magnitogamtarSi anu gularaSi Seqmnis cvlad magnitur nakads. gularis gavliT Sekruli magnituri nakadi ganWolavs meoreuli gragnilis xviebs

da daainduqcirebs masSi induq-ciis emZ-s. Tu meoreuli gragnilis boloebze mivaerTebT eleqtro-energiis raime mimRebs, maSin induqcirebuli emZ-is moqmedebiT meoreul gragnilSi mimRebis gavliT gaivlis Ddeni. es deni Tavis mxriv qmnis magnitur nakads, romelic pirvelad gragnilSi gamavali denis mier Seqmnili magnituri nakadis sawinaaRmdegoa.

transformatoris efeqturi muSaobisaTvis saWiroa rom pirvelad da meoreul gragnilebs Soris iyos idealuri induqciuri kavSiri da TiToeul maTgans unda gaaCndes maRali TviTinduqcia. es niSnavs, rom magnituri velis yvela Zalxazi, romelic moculia pirveladi gragni-liT aseve moculi unda iyos meoreuli gragniliTac. ase, rom mocemuli denis cvlilebis siCqaris dros TiToeuli gragnilis mier Seqmnili magnituri nakadi unda iyos didi. orive es piroba SeiZleba Sesruldes Tu orive gragnils davaxvevT rkinis gularaze ise, rogorc es gaakeTa faradeim Tavis pirvel eqsperimentebSi. rkina daaxloebiT 10 000 jer zrdis magnituri velis Zalxazebis raodenobas. aseTi masalebis Sesaxeb amboben, rom maT aqvT maRali magnituri SeRwevadoba.Ggarda amisa rkinis gularа axdens magnituri induqciis Zalxazebis lokalizebas, ris wyalobiTac transformatoris gragnilebi sivrceSi SeiZleba iyvnen erTmaneTisagan gayofili da amave dros induqciurad dakavSirebulni.

rkinis gularа warmoadgens yvela Tanamedrove Zaluri transformatoris ganuyofel nawils, xolo spilenZi da alumini maTi dabali eleqtruli winaRobis gamo iyvnen da rCebian gragnilebis dasamzadebel masalad.

idealuri transformatoris parametrebi mniSvnelovnad damokidebulia gularas Tvisebebze, saxeldobr, am dargSi iqna miRweuli yvelaze didi progresi. Ggularas dasamzadebeli masalis mniSvnelovani Tvisebaa magnituri SeRwevadoba, magnituri gaJRenTva, eleqtruli winaRoba da danakargebi histerezisze. Mmagnituri SeRwevadoba SeiZleba warmovidginoT rogorc magnitur velSi moTavsebuli masalaSi warmoqmnili magnituri Zalxa-

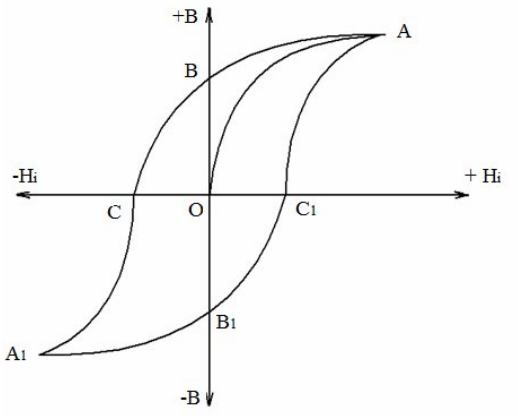
zebis raodenoba. Mmagnituri gaJRenTva es aris magnituri masalis mdgomareoba, romlis drosac misi damagniteba aRwevs zRvrul mniSvnelobas. Ees ori Tviseba gansazRvravs gularas Zalur maxasiaTeblebs. Ggularas masalas eleqtruli winaRoba mniSvnelovania imdenad, ramdenadac is saSualebas iZleva Semcirdes grigaluri denebiT gamowveuli danakargebi.

histerezisi magnitur masalebSi amcirebs transformatoris moqme-debis margi qmedebis koeficients. `damagnitebuli" atomebis jgufebs Soris urTierTqmedebis Sedegad masala agrZelebs damagnitebul mdgomareobaSi yofnas. Aamitom roca gare magnituri velis daZabuloba droebiT mcirdeba, masala myisve ver reagirebs. Aam Seyovnebas transformatorSi cvladi denis yovel ciklSi mivyavarT energiis danakargebTan.

transformatorebis gularebis srulyofis mTeli istoriis manZilze Catarebuli sainJinro kvlevebis ZiriTadi miznebi iyo magnituri SeRwevadobis, gaJRenTvis wertilisa da eleqtruli winaRobis amaRleba da histerezisze danakargebis Semcireba. Aam gamokvlevebSi mniSvnelovan rols TamaSobs mrudi, romelic grafikulad aRwers damokidebulebas dasamagnitebeli masalis iseT Tvisebebs Soris rogoricaa magnituri SeRwevadoba, magnituri gaJRenTva da histerezisi. es mrudi warmoadgens magnituri velis induqciasa da daZabulobas Soris damokidebulebis grafiks. cvladi denis TiToeuli ciklis damaxasiaTebel mruds aqvs S asos forma Seviwroebadi boloebiT (nax.1.2). misi daxris kuTxe Seesabameba magnituri SeRwevadobis sidides; is zeda wertili, (A) romelSic mrudi swordeba Seesabameba gaJRenTvis wertils, xolo $ABCA_1B_1C_1A$ mrudiT SemosazRvruli farTobi Seesabameba hosterezisS.

mkvlevarebs mudam ainteresebdaT, es Tvisebebi Tu rogor miekuTvneba masalis fizikur Tvisebebs. TiToeuli Tviseba damokidebulia elementerul magnitebs atomebs Soris urTierTqmedebis xasiaTze. es urTierTqmedeba ganisazRvreba rkinis kristaluri struqturisa da sxva elementebis – minaerTebis atomebis

arsebobiT. mecnierebas, am rTuli urTierTqmedebis Sesaxeb, magnituri domenebis Teoria ewodeba. es Teoria mecnierebs exmareba transformatorebisaTvis moZebuli iqnes ufro srulyofili masalebi.




nax.1.2. histerezisis maryuJi.

foladisagan damzadebuli Txeli firfitebi, romlisganac Sesdgeboda pirveli transformatorebis gularebi, xasiaTdebodnen histerezisze mniSvnelovani danakargebiT. SemdgomSi danakargebma TandaTan iwyes Semcireba foladis xarisxis dawvrilebiTi SerCevis xarjze da 1900 wlisaTvis SesaZlebeli gaxda danakargebis orjer Semcireba. amis Semdeg dadga masalis daZvelebasTan dakavSirebuli problema. eqspluataciis vadis zrdasTan erTad izrdeba danakargebi histerezisze.

1900 wlidan gularas masalis muSa maxasiaTeblebi mecnieruli kvlevebis Sedegad mniSvnelovnad iqna gaumjobesebuli.

transformatoris konstruqciis elementebi, romlebSic gadis eleqtruli deni (gragnilebi, gamomyvanebi da sxva) da romlebic erTmaneTTan SeerTebulia gansazRvruli sqemiT, qmnian transformatoris konstruqciis Camiwebuli nawilebisagan izolirebul eleqtrul wreds. saizolacio detalebi Sesrulebulia sxvadasxva saxis myari saizolacio masalebisagan: muyaos, qaRaldis, xis, getinaqsisa da sxva. zeTian transformatorebSi Casxmulia satransformatoro zeTi.

magnitogamtari masze Camocmul gragnilebTan erTad warmoadgens transformatoris aqtiur nawils, xolo danarCeni elementebi - pasiur nawils. gragnilebis sxvadasxva nawilebis SeerTeba erTmaneTTan da gadamrTvelebTan xdeba gamomyvanebis saSualebiT.

Zaluri transformatoris aqtiuri nawili moTavsebulia avzSi, romelic avsebulia zeTiT. Aavzis kedelze Cveulebriv damagrebulia zeTis gamacivebeli radiatorebi.

transformatorebis gragnilebis qselze misaerTeblad gamoyenebulia Semyvanebi, romlebic Sedgeba dengamtari nawilebisagan (Reroebi an milebi), faifuris safarisagan da sayrdeni miltuCasagan. Semyvanebi magrdeba avzis saxuravze an kedelze.Dam dros misi qveda nawili moTavsebulia avzis SigniT zeTSi, xolo zeda nawili avzis gareT haerSi. zeTiT avsebul Semyvanebs gaaCniaT sakuTari zeTis avtonomiuri moculoba.

gragnilebi izolirebulia rogorc erTmaneTisagan, ise gularasagan. Uufro maRali Zabvis gragnils ewodeba **maRali Zabvis (mZ) gragnili,** xolo ufro dabali Zabvis gragnils – **dabali Zabvis (dZ) gragnili.**

transformatoris pirveladi gragnilis xviaTa ricxvis Sefardebas meoreuli gragnilis xviaTa ricxvTan transformatoris transformaciis koeficienti ewodeba. transformaciis koeficienti gamoisaxeba formuliT:

$$K = W_1/W_2,$$

sadac $W_1$ – pirveladi gragnilis xviaTa ricxvia, xolo $W_2$ - meoreuli gragnilis.

Cveulebriv pirveladi da meoreuli gragnilebis Zabvebi sxvadasxvaa. Tu pirveladi Zabva naklebia meoreulze, maSin transformators ewodeba amamaRlebeli da $K<1$, xolo Tu metia – damadablebeli da $K>1$. Cveulebriv nebismieri transformatori SeiZleba gamoyenebuli iqnas rogorc amamaRlebel, ise damadablebel transformatorad. amamaRlebeli transformatorebi gamoiyeneba Sors manZilze eleqtroenergiis gadasacemad, xolo

damadablebeli – momxmareblebs Soris eleqtroenergiis gasanawileblad.

transformatorebis eqspluataciis dros iqmneba misi koeficientis cvlilebis (anu Zabvis regulirebis) saWiroeba. Zabvis regulireba erTi saxis transformatorebSi xdeba qselidan gamorTvis Semdeg, xolo sxva saxis transformatorebSi – datvirTvis qveS.

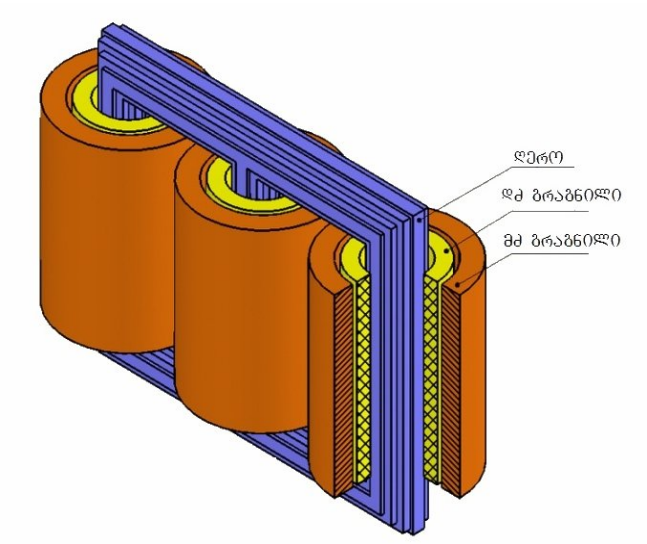
erTfaza transformatorebs gamoiyeneben sayofacxovrebo xelsawyo - danadgarebSi, denisa da Zabvis sazom transformatorebad; induqciuri, madanTermuli, ferosadnobi da sxva eleqtroRumelebis kvebisaTvis. Zalovani transformatorebi bunebrivi zeTis gacivebiT (nax.1.3.a) gamoiyeneba rkinigzebze avtoblokirebisa da signalizaciis aparaturis kvebisaTvis. aseT transformatorebSi gaTvaliswinebulia Zabvis regulireba. erTfaza transformatorebi gamoSvebulia 6, 10, 27 da 35 kv Zabvebze 0,63 – 10 kva simZlavriT. zemZlavri erTfaza transformatorebs 750 kv maRal Zabvamde ageben msxvili Tbo da hidroeleqtrosadgurebisa da damadablebeli qvesadgurebisaTvis. amasTanave eleqtroenergiis gadacemisaTvis ar gamoiyeneben erTfaza cvlad dens. Aam miznisaTvis farTo gamoyeneba hpova samfaza denma. Aamitom transformatorTa umetesoba samfazaa.

samfaza denis transformireba SesaZlebelia sami erTfaza transformatoris gamoyenebiT, romelTa pirveladi da meoreuli gragnilebi SeerTebulia samfaza sistemaSi varskvlavad (nax.1.1.b) an samkuTxedad. swored amgvarad muSaoben msxvil eleqtrosadgurebSi dayenebuli mZlavri erTfaza transformatorebi. isini pirveladi gragnilebiT CarTulni arian generatoris Sesabamis fazebTan; maTi meoreuli gragnilebi SeerTebulia varskvlavad da CarTulni arian sahaero gadacemis xazis Sesabamis fazebTan. umravles SemTxvevaSi samfaza transformatori warmodgenilia erT mTlianobaSi (nax.1.3.b). aseTi transformatoris magnitogamtari Sedgeba sami Rerosagan, romlebic zemodan da qvemodan Caketilia uRlebiT (nax.1.4.).

a) b)

nax.1.3. erTfaza (a) da samfaza (b) transformatorebis gare xedi.

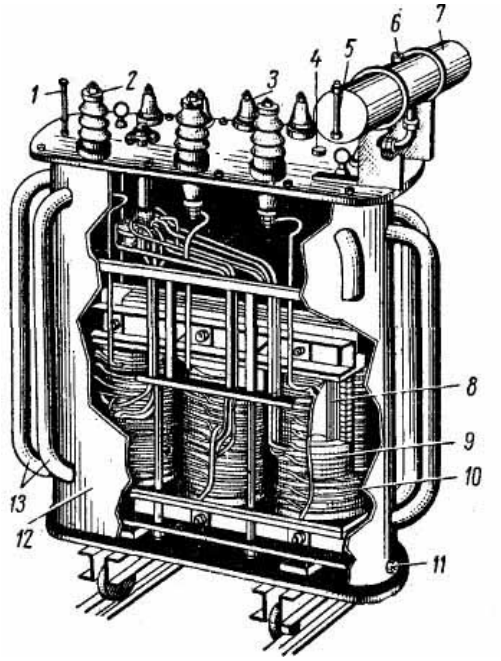
TiToeul Reroze Camocmulia erTi pirveladi da erTi meoreuli gragnili. Ppirveladi gragnilebi SeerTebulia varskvlavad an samkuTx-edad, aseve SeerTebulia meoreuli gragnilebi. Rero gragnilebiT warmoadgens erTfaza transformators. amitom yvelaferi is, rac zemoT iyo Tqmuli erTfaza transformatorze mTlianad vrceldeba samfaza transformatoris TiToeul fazaze. nax.1.4.-ze naCvenebia samfaza transformatoris gragnilebis magnitogamtarze ganlagebis sqema, xolo nax.1.5-ze moyvanilia samfaza transformatoris mowyobiloba.




B

nax..1.4. samfaza transformatoris gragnilebis magnitogamtarze ganlagebis sqema

samfaza transformatoris TiToeul ReroSi pirvelad gragnilSi gamavali denis mier aRiZvreba magnituri nakadi. TiToeuli pirveladi gragnili miekuTvneba samfaza sistemis erT romelime fazas, amitom gragnilebSi gamavali deni, iseve rogorc modebuli Zabvebi samfazaa da aqedan gamomdinare magnituri nakadebic samfazaa, romlebic erTmaneTis mimarT daZrulni arian $120^0$ – iT.




nax.1.5. samfaza transformatoris mowyobiloba: 1-Termometri; 2- maRali Zabvis gragnilis Semyvani; 3- dabali Zabvis gragnilis Semyvani; 4- avzSi zeTis Casasxmelis sacobi; 5- zeTis maCvenebeli; 6- safarToebelSi zeTis Casasxmelis sacobi; 7-safarToebeli; 8- magnitogamtari; 9- dabali Zabvis gragnili; 10- MaRali Zabvis gragnili; 11_ zeTis gamosaSvebi sacobi; 12- zeTis avzi; 12- zeTis gaciebis radiatorebi.

yvela zemoTmoyvanili miekuTvneba samfaza orgragnila transformatorebs, romelTac TiToeul Reroze gaaCniaT ori gragnili – pirveladi da meoreuli. aseT transformators SeuZlia gardaqmnas erTi sididis Zabva meore sididis Zabvad, magram bevr SemTxvevaSi es sakmarisi ar aris. Zalian xSirad saWiro xdeba gvqondes ori meoreuli Zabva, magaliTad, 110/35/10 kv.

## 1.2. transformatoris nominaluri monacemebi da teqnikuri maxasiaTeblebi.

Zalovani transformatorebi erTmaneTisagan gansxvavdebian nominaluri simZlavriT, Zabvis klasiT, MmuSaobis pirobebiTa da reJimebiT, konstruqciuli SesrulebiT.

transformatoris ZiriTadi monacemebi da maxasiaTeblebi naCvenebia saqarxno firfitaze. Ffirfita damagrebulia transformatoris avzze. Mmasze naCvenebia Semdegi parametrebi: transformatoris tipisAaRniSvna; fazaTa ricxvi; sixSire, hc; dayenebis saxe (Siga Tu gare); nominaluri simZlavre, kva; samgragniliani transformatorisaTvis TiToeuli gragnilis simZlavre; gragnilebis SeerTebis sqema da jgufi; Zabva nominalur safexurze da gragnilebis gamStoebebze, kv; nominaluri deni, a; mokled SerTvis Zabva procentebSi; gacivebis xerxi; mTliani transformatoris, zeTisa da aqtiuri nawilis masa, tona.

nominaluri simZlavrisa da Zabvis klasis mixedviT Zalovani transformatorebi pirobiTad iyofa cxrili 1.1 – Si moyvanil jgufebad (gabaritebad)

cxrili 1.1. Zalovani transformatoris jgufebi simZlavrisa da Zabvis mixedviT

| Ggabaritis nomeri | simZlavris diapazoni,kva | Zabvis klasi, kv |
|---|---|---|
| I | 100 - mde | 35- mde |
| II | 100 - 1000 | 35- mde |
| III | 1000 - 6300 | 35- mde |
| IV | 6300 –ze meti | 35- mde |
| V | 40000 – ze meti | 35 - 110 |
| VI | 40000 - 80000 | 330-mde |
| VII | 80000 - 200000 | 330 -mde |
| VIII | 200000 – ze meti | 330 –mde da zemoT |

warmoebis mier gamoSvebulia transformatorebi civ da tropikul klimatian raionebSi samuSaod, gare da Siga dayenebis, saerTo da specialuri daniSnulebis.

gaciebis mixedviT transformatorebi iyofian: mSral, zeTian da arawvadi Txevadi dieleqtrikiT.

yofil sabWoTa kavSirSi warmoebuli saerTo daniSnulebis transformatorebis asoiT aRniSvnebSi gvxvdeba Semdegi aRniSvnebi: А – avtotransformatori; О an Т - erTfaza an samfaza; Р – dabali Zabvis gaxleCili gragniliT; М – gaciebis saxe: haeris bunebrivi gaciebiT an zeTis bunebrivi cirkulaciiT; ДЦ - haeris an zeTis iZulebiTi cirkulacia Ц-wylisa da zeTis iZulebiTi cirkulacia; НДЦ d НЦ - zeTis mimarTuli dineba ДЦ da Ц sistemebSi; Т - gaciebis saxis aRniSvnis Semdeg – samgragnila transformatori; Н – datvirTvis qveS Zabvis regulatoriT; С – sakuTari moxmarebis.

nominaluri simZlavre da Zabvis klasi naCvenebia asoiTiAaRniSvnis Semdeg wiladis saxiT, romlis mricxvelSi naCvenebia nominaluri simZlavre kilovoltamperebSi, xolo mniSvnelSi Zabvis klasi kilovolttebSi.

pirobiTi aRniSvnebis magaliTebi: ТМ 1000/1074У1 – samfaza orgragnila transformatori zeTis bunebrivi gaciebiT. nominaluri simZlavre 1000 kva, Zabvis klasi 10 kv, 1974 wlis konstruqcia, gare dayenebis. ТРДНС 25000/3574Т1 – samfaza orgragniliani transformatori dabali Zabvis gaxleCili gragniliT, haeris iZulebiTi cirkulaciiT gacivebiT, Zabvis datvirTvis qveS regulirebiT, eleqtrosadguris sakuTari moxmarebisaTvis, nominaluri simZlavriT 25 mva, Zabvis klasi 35 kv, 1974 wlis konstruqcia, tropikuli SesrulebiT, gare dayenebis.

### 1.3. avtotransformatorebi

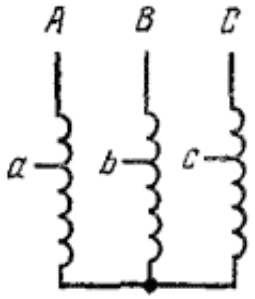
avtotransformatorebi warmoadgenen qvesadgurebis Zalovan danadgarebs, romelTa daniSnulebaa qselSi Zabvis donis cvlileba. avtotransformatori transformatoris variantia, romelSic pirveladi da meoreuli gragnilebi pirdapir aris SeerTebuli da erTmaneTTan aqvT aramarto eleqtromagnituri, aramed eleqtruli kavSiric da eleqtruli energiis gadacema pirveladi

wredidan meoreulze xdeba rogorc magnituri veliT, aseve eleqtruli gziTac. avtotransformatoris gragnils aqvs ramdenime gamomyvani (minimum 3), romelTa meSveobiT miiReba sxvadasxva sididis Zabvebi. Aavtotransformatoris upiratesobas warmoadgens maRali mqk, radgan simZlavris mxolod nawili eqvemdebareba gardaqmnas – es arsebiTad mniSvnelovania, roca Semavali da gamomavali Zabvebi erTmaneTisagan mcired gansxvavdebian. maT uaryofiT mxared iTvleba pirvelad da meoreul wredebs Soris eleqtruli izolaciis ar arseboba. samrewvelo qselebSi, sadac Camiwebuli nulovani sadenis arseboba aucilebelia, am faqtors mniSvneloba ara aqvs, magram mniSvnelovania, rom naklebia foladis xarji gularisaTvis, spilenZis xarji gragnilebisaTvis, mcire wona da gabaritebi, dabali Riribuleba. gansakuTrebiT efeqturia avtotransformatoris gamoyeneba im SemTxvevaSi, roca meoreuli Zabva didad ar gamsxvavdeba pirveladisagan.


Nnax.1.6. avtotransformatoris saerTo xedi

eqspluataciaSi farTo gamoyeneba hpoves avtotransformatorebma 220 kv da zemoT Zabvaze (nax.1.6). isini ZiriTadad, rogorc wesi mzaddeba samgragnila, romelTac garda eleqtrulad SeerTebuli gragnilisa gaaCniaT magniturad SeerTebuli gragnilic. Cveulebriv es gragnili dabali Zabvisaa, romelTanac SeiZleba mierTebuli iqnas generatori (eleqtrosadgurebSi), sinqronuli kompensatori (qvesadgurebSi) an SeiZleba gamoyenebuli iqnas

adgilobrivi momxmareblebis kvebisaTvis 35 kv Zabvamde. Nnax.1.7-ze mocemulia samfaza avtotransformatoris principuli sqema.




nax.1.7. samfaza avtotransformatoris principuli sqema.

qselidan kveba miewodeba A, B, C. Semyvanebze, xolo dabali Zabva moixsneba a, b, c gamomyvanebidan. samfaza avtotransformatorebSi gamoiyeneba mxolod gragnilebis varskvlava SeerTeba.

### 1.4. transformatoris dazianebebis ZiriTadi saxeebi

transformatoris tipiur dazianebebad iTvleba izolaciis, magnetogamtarebis, gadamrTveli mowyobilobebis, ganStoebebis, zeTvsebuli da faifuris Semyvanebis dazianebebi.

umetes SemTxvevebSi dazianeba uecrad ar xdeba, aramed raime araxelsayreli faqtoris xangrZlivi zemoqmedebiT. warmoqmnili defeqtis drouli gamovlena saSualebas iZleva miRebuli iqnes zomebi misi Semdgomi ganviTarebis AaRsakveTad da transformatoris muSaunarianobis SesanarCuneblad.

Zalovan transformatorebSi dazianebis yvelaze ufro gavrce-lebuli saxea maRalvoltiani Semyvanebis dazianeba. 110 kv da zeviT Semyvanebis dazianeba ZiriTadad dakavSirebulia qaRaldis fuZis datenianebasTan. Semyvanis SigniT tenis moxvedra SesaZlebelia SemWidrovebis uxarisxo SesrulebasTan, zeTis damatebisas daqveiTebuli dieleqtrikuli simtkicis satransformatoro zeTis CasxmasTan. transformatoris Semyvanebis dazianeba gansakuTrebiT saSiSia da iwvevs ara marto Semyvanebis, aramed TviT transformatoris mniSvnelovan dazianebas, rasac rogorc wesi, Tan axlavs xanZari. Dda mniSvnelovani materialuri

zarali. saeqspluatacio personali yovelTvis droulad ver amCnevs dazianebebs da amis gamo ver axdens dazianebuli Semyvanis gamocvlas.

dReisaTvis eqspluataciaSia hermetuli da arahermetuli zeTvsebuli Semyvanebi da agreTve Semyvanebi myari izolaciiT.

330-500 kv Zabvis zeTiT Sevsebuli Semyvanebi ZiriTadad ziandeba izolaciis eleqtruli garRveviT, rac gamowveulia arahermetul konstruqciaSi sinestis SeRweviTa da bakelitisa da qaRaldis izolaciis danestianebiT.Aamitom saWiroa izolaciis mdgomareobis drouli kontroli zeTis qromatografiuli analizi.

arahermetuli Sesrulebis Semyvanebi, romelTac mowyobilobis amuSavebis Semdeg aReniSneba izolaciis dieleqtrikuli danakargebis kuTxis tgδ – s da tevadobis mkveTri gauareseba, dauyonebliv unda Seicvalos.

arahermetuli Semyvanebis yvelaze ufro sust kvanZad iTvleba zeTiani hidrosaketisa silikageliani haersaSrobis daxmarebiT zeTis dacvis sistema. xangrZlivi eqspluataciis dros, gansakuTrebiT silikagelis dagvianebiT gamocvlis SemTxvevaSi, zeTi teniandeba, uaresdeba misi saizolacio maxasiaTeblebi, ris Sedegadac zeTSi SeiZleba aRiZras nawilobrivi ganmuxtvebi. Semdgom-Si qaRaldis izolaciis zedapirze iwyebs warmoqmnas e.w. “mcocavi” ganmuxtva: izolaciis dazianebuli zedapiris erTi an ramdenime sawyisi wertilidan cocaven gawvis adgilebi, romlebic izolaciis Sesustebul zedapirebze qmnian rTul naxats. rogorc ki “mcocavi” ganmuxtva miuaxlovdeba Camiwebul nawils, xdeba izolaciis garRveva mokled SerTvis aRZvriT.

zeTis saizolacio maxasiaTeblebis mniSvnelovani gauaresebis SemTxvevaSi garRveva SeiZleba moxdes “mcocavi” ganmuxtvis warmoqmnis gareSec. Aanalogiuri dazianeba SeiZleba moxdes im SemTxvevaSic, Tu Semyvanis remontis dros qaRaldis izolacia iyo cudad gamSrali.

hermetuli Semyvanebi eqspluataciaSi naklebad Sromatevadi da ufro saimedoa, vidre arahermetuli. isini umetesad ziandebian

wnevis avzebis silfonebSi warmoqmnili aluminis mtveriT. hermetuli Semyvanebis mdgomareoba da muSaunarianoba ganisazRvreba da kontroldeba manometris CvenebiT, romelic muSaobs indikatoris reJimSi. zeTis wnevis mkveTri amaRlebis dros, romelic dakavSirebuli ar aris temperaturis awevasTan, transformatori dauyonebliv gamoyvanili unda iqnas muSaobidan da unda moxdes defeqturi Semyvanis Secvla.

rogorc hermetul aseve arahermetul SemyvanebSi zeda sakontaqto sarWis damagrebis zonaSi SeiZleba adgili hqondes hermetulobis darRvevas. darRveva SeiZleba moxdes transformatoris yvelaze maRal wertilSi mdebare kvanZis araswori awyobis Sedegad. aRniSnul kvanZSi zeTis Warbi wneva, gansakuTrebiT civ periodSi (safarToebelSi am dros zeTis done minimaluria), nulTan axlosaa. roca hermetuloba darRveulia, maSin sinestem atmosferodan gaJonos zeTSi, ris Sedegadac transformatoris izolacia dairRveva.

110 – 150 kv Zabvis araHhermetul SemyvanebSi 15-20 wlis muSaobis Semdeg cvdeba SemWidroebebi, maT Soris zeda kvanZSi, ris Sedegadac sineste aRwevs safarToebelSi, aqedan ki igi nawildeba Semyvanis MmTel moculobaSi, rac iwvevs izolaciisa da zeTis danestianebas. zeTvsebuli Semyvanebi ziandebian agreTve Semyvanis qveda ekranis zonaSi Sualeduri milisis axlos Siga izolaciis garRveviT.

moqnili xazuri Sleifis dasaSvebze metad daWimvis gamo gamowveuliMmeqanikuri zemoqmedebisa da mkveTrad cvalebadi rTuli klimaturi pirobebis gamo xdeba WanWikuri SeerTebisa da sakontaqto kvanZebis moSveba da imavdroulad Semyvanis hermetulobis darRveva. Kkontaqtis kuTxvilis (“rezba”) mdgomareobis gauaresebisa da koroziis gaCenis Sedegad kontaqtis adgilze izrdeba gardamavali winaRoba, rac iwvevs Zlier gaxurebas da transformatoris Semyvanis zeda nawilis bunikidan gragnilis gamomyvanis gamodnobas. Aam defeqtis SeumCnev-lobiT transformatori SeiZleba Zlier daziandes. amitom perioduli daTvalie-

rebisa da remontebis dros saWiroa gansakuTrebuli yuradReba mieqces gragnilebis gamomyvanebis bunikebTan mirCilvis xarisxs, gakontroldes momWerebis kontaqtis kuTxvilebis mdgomare-oba da droulad SevcvaloT rezinis SemWidroebebi.

sxvadasxva mizezebis gamo, ZiriTadad eqspluataciisas,xdeba faifuris safaris, zeTis maCvenebeli minis, manometrisa da sxvaTa dazianeba, wiboebis Camotexva.

remontisa da montaJis dros faifuris safaris wanacvlebis Tavidan acilebis mizniT dauSvebelia personalis gadaadgileba uSualod safaris wiboebze. amisaTvis unda gamoviyenoT kibeebi an specialuri asawevi moednebi.

Zveli zeTvsebuli Semyvanebis axliT (naklebi zomebiT, rogorc simaRliT, aseve diametriT) Secvlis dros saWiroa gaTvaliswinebuli iqnes maTi sigrZe da unda moxdes maTi morgeba (gamomyvanis sigrZis damokleba). Tu es ar moxdeba, maSin axali Semyvanis dayenebis Semdeg gaCndeba maryuJi, ris gamoc dairRveva saizolacio daSoreba, rasac mivyavarT transformatoris konstruqciis am ubanze izolaciis garRvevamde.

35 kv Zabvamde Semyvanebi rogorc wesi ziandeba dauSvebeli meqanikuri zemoqmedebiT, rac gamoixateba faifuris safaris dazianebaSi. Sedegad transformatoridan iwyeba zeTis dineba. transformatorTan gare salteebis uxeSad SeerTebisas Semyvanis zeda kontaqtis sarWis kuTxvili nawili swrafad cvdeba.

transformatoris dazianebis aseve gavrcelebul saxes warmoadgens datvirTvis qveS Zabvis regulirebis mowyobilobis dazianeba. kontaqtebis araswori regulirebis,iSviaTi gadarTvebis gamo kontaqtebis zedapirebze gaCenili Jangeulebis afskebisa da kinematikur sqemebSi darRvevebis Sedegad amomrCevlis kontaqtur sistemaSi SeiZleba gaCndes darRvevebi.

gadamrTveli mowyobilobebi sakmaod rTulia da moiTxovs dawvrilebiT gawyobas, Semowmebasa da specialuri gamocdebis Catarebas. rogorc analizma aCvena Zabvis regulirebis mowyobilobis (Zrm) yvelaze arasiamedo elementia amZravi. mis mtyunebaTa

mizezebia: amamuSavebl is kontaqtebis miwebeba; muSta meqanizmebis dazianeba; sabo l oo da damcavi amomrTve l ebis mtyuneba; sinest is gamo amZravis e leqtroZravis xviebis mokled SerTva; amZravis mowyobi l obis e lementebis arasakmarisi gaTboba; kontro lerebSi meqanikuri cveTis gamo mwyobridan gamodis gorgo laWi; amZravis saxuravis arasakmarisi hermetu l obis dros amZravis aparatura da sxvadasxva SemaerTebe l i xundebi ifareba JangiTa da mtveriT; adgi l i aqvs zeTis dinebas mdgomareobis maCveneb l is minis qvemodan da Wiaxraxnis kvanZSi; amomrCevi kontaqtebis arasakmarisi daWeris gamo adgi l i aqvs dawvas.

am mowyobi l obis kontaqtori SeiZ leba daziandes misi kontaqtebis sistemisa da kinematikuri sqemis araswori regu l irebiT, agreTve sat ransformatoro zeTis dagvianebu l i gamocv l iT. Kkontaqtoris damxmare da rkal mqrobi kontaqtebis amuSavebas Soris dro gadarTvisas Seadgens wamis meaTed nawi l ebs. Tu kontaqtorSi zeTma dakarga Tavisi rkal mqrobi Tvisebebi, maSin rkal is qrobis dro gaiwe l eba da t ransformatoris maregu l irebe l i gragni l is mezobe l i ganStoebebi aRmoCndebian erTmaneTTan SeerTebu l i ara rkal mqrobi rezistoris gav l iT, aramed e leqtru l i rka l iT, rasac mivyavarT mZime avariamde, t ransformatoris gragni l ebis deformaciamde.

kontaqtoris WanWikebis konstruqciu l i Sesru l eba da maTi damagrebis arasakmarisi simtkice mniSvne l ovnad arTu l ebs maT revizias da amitom saWiro xdeba mTe l i gadamrTve l i mowyobi l obis amoReba t ransformatoris avzidan.

u fro mZime Sedegebamde mivyavarT t ransformatoris mTavari izo l aciisa da gragni l ebis dazianebas. cudad gamomSra l i e leqtro-muyao an xviebs Sorisi qaRa l dis izo l acia da maT fenebs Soris zomebis daucve l oba,sustad daxveu l i izo l acia, gaWuWyianebu l i an danestianebu l i sat ransformatoro zeTi, iwveven myari izo l aciis dazianebas, “mcocavi” ganmuxtvis warmoSobasa da Semdgom garRvevas.

transformatoris dazianebas iwvevs agreTve daRRvevebi gaciebis sistemaSi Ggaciebis sistema transformatoris mniSvnelovani kvanZia, romelic uzrunvelyofs mocemul temperaturul reJims. gaciebis sistemis dazianebam SeiZleba migviyvanos qaRaldis izolaciisa da zeTis mniSvnelovan Tbur daZvelebamde, rac amcirebs transformatoris winaaRmdegobas eleqtruli da dinamiuri zemoqmedebebis mimarT.

gaciebis sistemis elementebis damaxasiaTebeli dazianebebia: zeTis dena da gaJonva, rasac mivyavarT transformatoris gamorTvamde. Aam defeqtis gamovlenis mizezi SeiZleba iyos SeduRebis nakerebis defeqtebi, gaciebis sistemis elementebis gamaciebeli zedapirebis deformacia, zeTis gaciebis sistemis hermetulobis darRveva, ventilatoris frTebis dauSvebeli vibracia, romelsac Tan axlavs frTebis gatexva.

gaciebis sistemis eleqtrotumboebi warmoadgenen gaciebis sistemis naklebad saimedo kvanZs. sustad Camocmuli sakisari iwvevs rotoris statorTan modebas, ris gamoc warmoiSveba meqanikuri mtveri da burbuSela, romelic miitaceba eleqtrotumboSi gamdinare zeTiT da xvdeba transformatoris avzSi; daileqeba ra izolaciaze, amcirebs mis eleqtrul simtkices da xels uwyobs transformatoris dazianebas. amasTanave aRiZvreba RerZuli datvirTva lilvze, rac xels uwyobs radialur - sabjeni sakisrebis cveTas.

energetikuli simZlavreebis mudmiv zrdasTan erTad izrdeba mokled SerTvis simZlavreebi. simZlavreebis zrdisa da agreTve gragnilebis Sesustebuli dawnexvis dros gragnilebis eleqtrodinamiuri mdgradoba gareSe mokled SerTvis denebis mimarT SeiZleba arasakmarisi aRmoCndes da deformacia ganicados gragnilma, romelic mokled SerTvamde karg mdgomareobaSi imyofeboda.

125 mva da zemoT simZlavris axali tipis transformatorebis didi umravlesoba (da yvela Zveli tipis) Semowmebuli ar aris eleqtrodinamiur simtkiceze. aseTi transformatorebis meqanikuri simtkice rogorc wesi mocemulia mxolod gaangariSebiT.

Aamitom mokled SerTvis zemoqmedebis Sedegad Zalovani transformatorebis dazianebis albaToba SenarCunebulia. eqspluataciis praqtikaSi xSirad gvxvdeba transformatorebis xviaTaSorisi da koWaTaSorisi mokled SerTvis Sedegad gamowveuli dazianebebi. statistikam aCvena, rom transformatorebi xviaTaSorisi mokled SerTvis Sedegad ziandebian rogorc eqspluataciis dasawyisSi, aseve xangrZlivi eqspluataciis Semdeg. xviaTaSorisi mokled SerTvis mizezebi SeiZleba iyos sxvadasxva: koWis xviis izolaciis Sesusteba, romelic iwvevs sadenis defeqts; mokled SerTvis denebis zemoqmedebiT koWebis deformacia; xviebis izolaciis arasakmarisi sisqe; gadaWarbebuli eleqtruli, Tburi da vibraciuli zemoqmedeba; izolaciis danestianeba da gaWuWyianeba.Aam faqtorebis erToblivi zemoqmedebiT xviaTaSorisi mokled SerTvis albaToba mniSvnelovnad izrdeba.

radganac transformatoris muSaobaSi mTavari da xviaTaSorisi izolaciis dazianeba iwvevs mZime Sedegebs, amitom am saxis dazianebebis droulad gamovlenas didi yaradReba eqceva.

transformatoris magnitogamtarebi ziandeba gadaxurebis Sedegad foladis furclebs Soris laqis afskis daSlisa da damwnexi sarWebis izolaciis darRvevis gamo. foladis dazianebas mivyavarT naklebad mZime Sedegebamde, rac ZiriTadad dakavSirebulia avzis SigniT mokled SerTuli konturebis SeqmnasTan. Kkonturi SeiZleba Seiqmnas rogorc magnitogamtaris paketis SigniT, aseve konstruqciuli metalis romelime detalisa da magnitogamtaris Camiwebis elementis gavliT. Mmokled SerTuli konturi iwvevs gazrdil adgilobriv gadaxurebas, gansakuTrebiT kontaqtebis adgilebSi, rac auaresebs satransformatoro zeTis Tvisebebs. Tu defeqti droulad ar iqna gamosworebuli, maSin SeiZleba moxdes transformatoris myari izolaciis dazianeba.

transformatorebis daproeqtebis dros safarToebelis moculoba ganisazRvreba angariSiT da ar mowmdeba specialuri Tburi gamocdebiT. Aamitom transformatoris safarToebelis tevadoba

yovelTvis ar Seesabameba avzSi zeTis moculobis cvlilebas garemos temperaturisa da datvirTvis yvela saxis rxevebis dros.

safarToebelSi zeTis donis dasaSvebze metad awevas mivyavarT arasasurvel movlenebamde:

afskuri dacvis mqone transformatorebSi xdeba afskis sruli SekumSva da damcavi sarqvelis amuSaveba. Ddefeqturi sarqvelis amuSavebis Semdeg ar xdeba misi Semdgomi daxurva, ris gamoc zeTis gaJonvis Sedegad gamoirTveba transformatori.

transformatorebSi, romelTac gaaCniaT Cveulebriv haersaSrobiT dacva, safarToebelSi zeTis donis awevis SemTxvevaSi zeTis SeRweva haersaSrobSi da Semdgom zeTi gadmodis gareT. datvirTvis gazrdiTa da zeTis moculobis gafarToebis gamo izrdeba zeTis wneva, irRveva gamosabolqvi milis da zeTi gamoifrqveva gareT. qvesadgurebSi, sadac ar aris morige personali, dazianebuli diafragmis gavliT safar-ToebelSi aRwevs sineste da xdeba zeTis da Semdgom izolaciis danestianeba. amitom Znelad misadgom adgilebSi awarmoeben didi moculobis safarToeblebis dayenebas.

transformatoris dazianebebi, romlebic aRmoifxvreba transformatoris gaTiSvis gareSe, pirobiTad miekuTvneba sxva dazianebebs.

aseTi tipis yvelaze ufro gavrcelebul dazianebas miekuTvneba konstruqciis kvanZebis sxvadasxva gasarTebSi zeTis dineba cudi xarisxis zeTmedegi rezinis gamo, romelic AaRmoifxvreba gasarTebis qanCebis moWeriT.

SemamWidroebeli safenis wanacvlebiT gamowveuli damcavi sarqvelis araswori muSaoba, iwvevs transformatoridan zeTis dinebasa da gaJonvas.

aRsaniSnavia, rom transformatorebis diagnostikis mniSvnelovani da sakmaod obieqturi meTodia misi gamokvleva Tbovizoris daxmarebiT infrawiTel diapazonSi, romlic saSualebas gvaZlevs qselidan gamorTvis gareSe davinaxoT Zalovan transformatorebSi lokaluri gacxelebebi da SeerTebis gardamavali

winaRobebi. ukanasknelI wlebis ganmavlobaSi infrawiTeli teqnikis xelsawyoebis daxmarebiT energosistemebSi SemCneuli iqna aTi aTasobiT ganviTarebadi defeqtebi, romelTagan aTass SeeZlo gamoewvia msxvili avaria.

ufro da ufro farTod iwyeba Zalovani transformatorebis diagnostikaSi nawilobrivi ganmuxtvebis meTodebisa da aparaturis gamoyeneba. eleqtronul-optikuri meTodi da cifruli aparatura gansakuTrebul adgils iWers eleqtruli ganmuxtvebisa da Tburi procesebis kontrolis dros gazomvis distanciurobisa da operatiulobis procesebisa da maRali informaciulobis wyalobiT.

### 1.5. Zalovani transformatorebis kontrolis ZiriTadi meTodebi.

Zalovani transformatorebis gamokvleva SeiZleba moxdes remontSi gadayvaniTa da mis gareSe. Zalovani transformatoris gamokvleva remontSi gadayvaniT xdeba eleqtruli da qimiuri gamocdebis meTodebiT.

**aucilebeli eleqtruli gamocdebis CamonaTvalSi Sedian [5]:**

- yvela gragnilis winaRobis gazomva da absorbciis koeficientis gansazRvra;
- gragnilebis dieleqtrikuli danakargebisa da izolaciis tevadobis gazomva;
- satransformatoro zeTis gamrRvevi Zabvis gansazRvra;
- Txevadi dieleqtrikis dieleqtrikuli danakargebis kuTxis tangensis gansazRvra;
- gadamrTveli mowyobilobis yvela ganStoebaze mudmivi deniT gragnilebis winaRobis gansazRvra;
- mcire erTfaza agznebis dros uqmi svlis denisa da danakargebis gansazRvra;
- mokled SerTvis sruli winaRobis gansazRvra;
- transformaciis koeficientis gansazRvra;
- maRalvoltiani SemyvanebisaTvis izolaciiswinaRobis gazomva da absorbciis koeficientis gansazRvra;

- maRalvoltiani SemyvanebisaTvis izolaciis dieleqtrikuli danakargebisa da tevadobis gansazRvra;
- 50 hc sixSiris aweuli ZabviT izolaciis gamocda (sruli kapitaluri remontis dros gragnilebis mTliani gamocvlis SemTxvevaSi);

damatebiTi eleqtruli gamocdebis CamonaTvalSi Sedian:

- eleqtruli meTodebiT nawilobrivi ganmuxtvis donisa da adgil-mdebareobis gansazRvra [6];
- gragnilebis deformaciis gamovlena transformatoris gardamavali funqciis analizis gziT, sixSiruli da impulsuri maxasiaTeblebisa da aweuli Zabvis dros nawilobrivi ganmuxtvis gazomvis [7], mokled SerTvis induqciuri da sruli winaRobis gansazRvris meTodebis, dabalvoltiani impulsebis, magnituri induqciis daxmarebiT [8];
- transformatoris gare magnituri velis gazomvis gziT gragnilebSi xviebs Soris mokled SerTvis gansazRvra [9];
- Zalovani transformatorebis elementebis vibraciis gansazRvra [10];
- gadamrTveli mowyobilobis mdgomareobis Sefazeba qarxana-damam-zadeblid moTxovnebis mixedviT: wriuli diagramis gadaReba, sakontaqto sistemis oscilografireba [17];

aucilebel qimiur gamocdebSi Sedian:

- myari izolaciis tenianobis Sefaseba [12];
- zeTSi gaxsnili airebis qromatografiuli analizi [13];
- Txevadi dieleqtrikuli mJavuri ricxvis gansazRvra [14];
- wyalSi sxnadi mJavebis gansazRvra [15];
- raodenobrivi da xarisxobrivi tenSemcvelobis gansazRvra [16];
- Txevadi dieleqtrikis afeTqebis temperaturis gansazRvra [17];
- Txevadi dieleqtrikis antimJavuri misarTis gansazRvra (mowyobilobaSi Casxmamde) [18];
- Txevadi dieleqtrikis sisufTavis klasis gansazRvra [19];
- Txevadi dieleqtrikSi gaxsnili Slamis Semcvelobis gansazRvra [20];

- Txevadi dieleqtrikSi airSemcvelobis gansazRvra qarxanadamamzadeblis instruqciis Sesabamisad [21];
- gragnilebis qaRaldis izolaciis mdgomareobis Sefaseba furanuli SenaerTebis [22] da polimerizaciis xarisxis [23] mixedviT;

**Txevadi dieleqtrikebis damatebiTi gamocdebis CamonaTvalSi Sedian:**

- simRvrivis gansazRvra [24];
- infrawiTeli speqtroskopiis daxmarebiT daZvelebis produqtebis gansazRvra [25];
- avzidan da maRalvoltiani Semyvanebidan amoRebuli satransformatoro zeTis dieleqtrikuli danakargebis kuTxis tangensis [26], kuTri moculobiTi gamtarobis [27] gazomva sxvadasxva temperaturuli reJimis dros;

Zalovani transformatorebis uwyveti kontrolis (online monitoring) meTodebs miekuTvnebian:

- Tbovizoruli [28];
- vibraciuli [29];
- zeTSi gaxsnili airebis Semcvelobis gansazRvra, transformatorSi temperaturisa da tenianobis kontroli [30];
- akustikuri [31];
- nawilobrivi ganmuxtvis [32];
- Zabvis qveS regulatoris meqanikuri mdgomareobis sixSiruli meTodiT Sefaseba [33];
- yvelaze ufro gacxelebuli wertilebis gansazRvra optikurboWkovani gadamwodebiT [34];
- maRalvoltiani Semyvanebis kontroli muSa Zabvis qveS fazebs Soris gamtarobisa da danakargebis kuTxis gziT [35];
- transformatoris avzis siaxloves magnituri velis induqciis gazomva [36];
- zemaRali sixSiris eleqtromagnituri gamosxivebis maxasiaTeblebis kontroli [37] da sxva.

ukanasknel xanebSi intensiurad viTardeba da inergeba didi simZlavris Zalovani transformatorebis uwyveti kontrolis meTodebi Tanamedrove kompiuteruli teqnologiisa da monacemebis avtomaturi aRebis, damuSavebisa da analizis gamoyenebiT.

am meTodebis gamoyeneba xorcieldeba transformatoris gareT dayenebuli sxvadasxva saxis gadamwodebis gamoyenebiT.

### 1.6. transformatoris mdgomareobis diagnostikis xerxebi

transformatoris diagnostikis qveS igulisxmeba sxvadasxva teqnikuri saSualebebis gamoyenebiT Catarebul RonisZiebaTa sistemis meSveobiT misi mdgomareobis Semowmeba da Sefaseba.

daxuruli zeTiani trasformatorebis gamoCenisTanave aRiZra maTi mdgomareobis kontrolis problema. romelime Siga kvanZis daTvaliere-bisaTvis, saWiro iyo transformatoris gamorTva, zeTis Camosxma, reviziis Catareba da Semdeg zeTis ukan Casxma. yvela es operacia unda Sesruldes mravalricxovani wesebis dacviT da bolos CarTvis win unda moxdes transformatoris gaSroba. zeTiani transformatorebis masiuri eqspluataciis gariJraJze saremontod Zalian xSirad uxdebodaT transformatoris gaxsna. amasTanave unda aRiniSnos, rom rac ufro xSirad ixsneba transformatori, miT ufro didia misi dazianebis albaToba.Aam procesTan dakavSirebulma siZneleebma da mouxerxeblobam saWiro gaxada moZebniliyo da ganviTarebuliyo transformatoris mdgomareobis kontrolis iseTi meTodebi, romlebic ar moiTxovdnen mis gaxsnasa da zeTis Camosxmas. Ees SesaZlebeli gaxda mas Semdeg, rac didi warmatebiT ganviTarda transformatoris mdgomareobis Semowmebisa da Sesabamisi maCveneblebis gansazRvris xerxebi, anu sxvagvarad rom vTqvaT, diagnostikis dargSi miRweuli warmatebebis Sedegad, romelTa mixedviTac SesaZlebelia vimsjeloT agregatis muSaunarianobaze.

diagnostikaSi gamoyenebulia martivi vizualuri, meqanikuri, fizikuri, qimiuri da mdgomareobis kontrolis sxvadasaxva xerxebi, agreTve maTi kombinaciebi. magaliTad, satransformatoro

zeTis danestianeba SeiZleba gansazRvruli iyos silikagelis feris cvlile-biT an qimiuri analizis gziT. zeTSi an myar izolaciaSi nawilobrivi eleqtruli muxtis arseboba SeiZleba gansazRvruli iqnes nawilobrivi ganmuxtvis indikatoris daxmarebiT, uSualo gazomviT an zeTSi gaxsnili airebis qromatografiuli analiziT.

Cveulebriv praqtikuli miznebisaTvis ama Tu im parametris kontrolis xerxebidan arCeven yvelaze martivs, xolo dawvrilebiTi Semowmebisas, roca saWiroa defeqtis xasiaTisa da adgilis dazusteba, gamoiyeneben ufro rTul xerxebs.

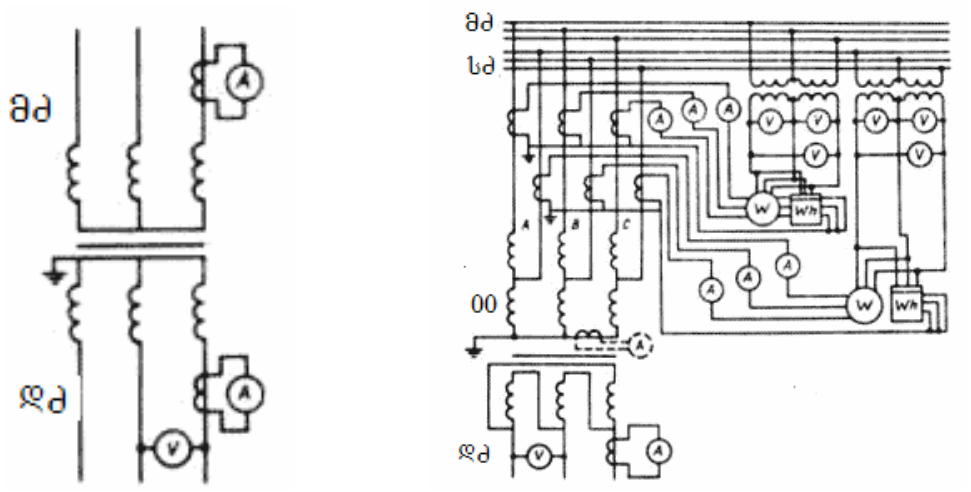
transformatoris mdgomareobis kontroli atarebs kompleqsur xasiaTs. Cveulebriv is iwyeba misi damzadebis stadiaze. swored maSin mowmdeba saizolacio da aqtiuri masalebis, calkeuli kvanZebisa da detalebis da agreTve awyobis xarisxi. Mmza transformatori eqvemdebareba kompleqsur Semowmebas, romelic tardeba diagnostikis yvela saWiro saSualebebiT aRWurvil qarxana- damamzadeblis sacdel sadgurSi.

transformatoris transportirebis dros xorcieldeba misi kontroli hermetulobasa da meqanikur zemoqmedebebze. Aadgilze mitanili transformatori agreTve moiTxovs misi mdgomareobis kontrols rogorc Senaxvisas, aseve montaJis procesSi teqnikuri dokumentaciis Sesabamisad. montaJis damTavrebis Semdeg eqspluataciaSi Seyvanis win transformatoris mdgomareobis diagnostikis mizniT igi gamoicdeba eleqtrodanadgarebis mowyobis wesebiT gaTvaliswinebuli moculobiT. Utransformatoris mdgomareobis Semowmebis ufro didi moculobis samuSaoebi srulideba eqspluataciis procesSi.

winamdebare saxelmZRvaneloSi ganxilulia transformatoris diagnostikaSi dReisaTvis gamoyenebuli xerxebi. gansakuTrebuli yuradReba miqceulia imisaken, Tu miRebuli Sedegebis mixedviT rogor SevafasoT transformatoris mdgomareoba da gavakeToT daskvna misi Semdgomi eqspluataciis SesaZleblobis Sesaxeb.

transformatoris mdgomareobis Semowmebis wesi moyvania mravali direqtiuli meToduri masalebiT. Yyvelaze ufro srulad es sakiTxebi ganxilulia transformatorebis eqspluataciis instruqciasa da eleqtromowyobilobis gamocdis normebSi.

muSaobis reJimis Sesafaseblad transformatorebi aRWurvilia saWiro sakontrolo-sazomi xelsawyoebiT. maTi mierTebis wertilebisa da adgilebis raodenoba damokidebulia maT daniSnulebaze, simZlavreze, transformatoris dadgmis punqtsa da sxva faqtorebze. 1 mva da zeviT simZlavris transformatoris TiToeuli Zabvis mxareze ayeneben erT ampermetrs, zogierT SemTxvevaSi SeiZleba dayenebuli iqnas TiToeul fazaze. Zabvis kontroli Cveulebriv xorcieldeba Semkreb salteebze dayenebuli voltmetrebiT. calke mdgom transfor-matorebze voltmetrebs ayeneben mxolod Ddabali Zabvis mxares. Nnax.1.8.a - ze moyvania 6/0,4 kv 1 mva simZlavris transformatoris eleqtrosazomi xelsawyoebis CarTvis umartivesi sqema.



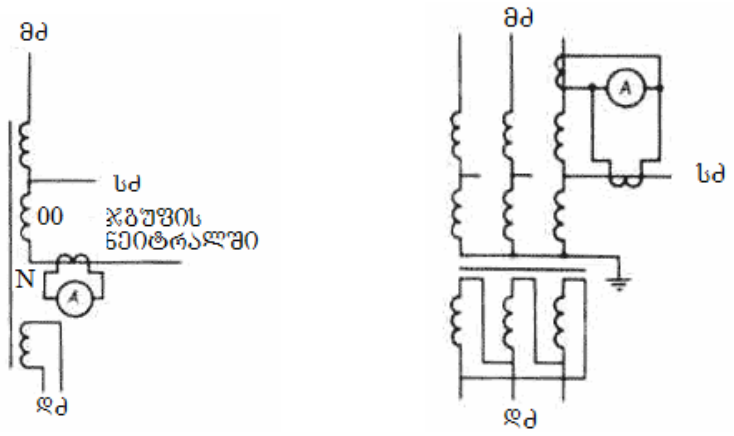
Aa) b)

Nnax.1.8. eleqtrosazomi xelsawyoebis CarTvis sqema. Aa- 6/0,4 kv Zabvisa da 1 mva simZlavris transformatorTan; b- 220/110/10 kv Zabvis samgragnila avto-transformatorTan.

vatmetrebi da varmetrebi dayenebulia eleqtrosadguris amwev da 110 kv da zeviT transformatorebze. Aaqtiuri da reaqtiuli energiis mricxvelebi dayenebulia samgragniliani transformatorebis maRali da saSualo Zabvis mxares, xolo

orgragnilianis – maRali Zabvis mxares.Ddamabo loebel transformatorebSi dayenebulia dabali Zabvis mxares. Nnax.1.8.b-ze moyvanilia 220/110/10 kv samgragnilian avtotransfo-rmatorTan eleqtrosazomi xelsawyoebis CarTvis sqema. maRali Zabvis mxares CarTulia sami ampermetri, vatmetri da aqtiuri energiis mricxveli. Zabvebi izomeba Zabvis transformatoris salteebTan CarTuli sami voltmetriT. aseTive xelsawyoebi CarTulia saSualo Zabvis mxares. dabali Zabvis mxares dayenebulia TiTo ampermetri da voltmetri.

samgragnila avtotransformatorebSi, gansakuTrebiT maSin, roca dabali Zabvis gragnilTan mierTebulia generatori an sinqronuli kompensatori da mTeli simZlavre gadaecema saSualo Zabvis mxares an moedineba saSualo Zabvis mxridan, saWiroa gakontroldes avtotran-sformatoris gragnilis saerTo nawilis (00 gragnilis, romelsac zogjer pirobiTad saSualo Zabvis gragnils uwodeben. nax.9.7.b) datvirTva. zogierTi reJimis dros SeiZleba adgili hqondes SemTx-vevas, roca saSualo Zabvis mxares deni araRemateba nominalurs, xolo saerTo nawilis deni aRemateba dasaSveb mniSvnelobas. Aam dros deni izomeba erTi specialurad CarTuli ampermetriT. EerTfaza avtotransformatorebSi ampermetri irTveba jgufis erTi avtotransformatoris neitralis SemyvanSi dayenebuli denis transformatoris gavliT (nax.1.9.a). samfaza avtotransformatorebSi ampermetri irTveba maRali da saSualo Zabvis mxares xazuri denebis jamze denis transformatorebis gavliT, romelTac aqvT transformaciis erTnairi koeficienti (nax.1.9. b). ampermetri SeiZleba CairTos agreTve avtotransformatoris erTi fazis neitralur sadenSi CarTuli denis transformatoris gavliT ise, rogorc naCvenebia punqtiriT nax.1.9.b-ze.




Aa) b)

Nnax.1.9. avtotransformatoris gragnilis saerTo nawilSi gamavali denis kontrolisaTvis ampermermetris CarTvis sqema: a- erTfaza avtotransformatoris neitralis Semyvanze; b – samfaza avtotransformatoris maRali da saSualo Zabvis mxaris xazuri denebis jamze.

garda eleqtrosazomi xelsawyoebisa transformatorze dayenebulia kontrolis sxva saSualebebic. zeTis done ganisazRvreba isriani zeTmaCvenebliT an zeTsazomi miniT, romelic moTavsebulia safarToeblis torsze. zeTis zeda fenebis temperatura mowmdeba manometruli masignalebeli Termometris CvenebiT, romelsac gaaCnia ori gadasaadgilebeli sasignalo kontaqti. transformatoris hermetul zeTvsebul Semyvanebze zeTis wnevis kontrolisaTvis dayenebulia manometrebi. satransformatoro zeTis mdgomareobis Sesaxeb mniSvnelovan informacia iZleva indikatoruli silikagelis feri, romlis Secvlis SemTxvevaSi saWiroa zeTis Secvla.

transformatoris SeberviTi gaciebis mowyobilobebi aRWurvilia gaciebis sistemis muSaobis Sewyvetis, sarezervo gaciebisa da sarezervo kvebis wyaros CarTvis signalizaciis mowyobilobebiT, xolo zeTis iZulebiTi gaciebisas - TiToeuli eleqtrotumbos CarTva-gamorTvis, mwyobridan gamosuli eleqtrotumbos magier sarezervos CarTvis, yvela muSa eleqtrotumbos muSaobis Sewyvetisa da sarezervo kvebis wyaros CarTvis signalizaciiT. gaciebis yvela sistemaze, romelTac gaaCniaT eleqtrotumbo, sa-

dawneo milze zeTis wnevis kontrolisaTvis dayenebulia manometrebi.

eqspluataciis dros transformatorebis mdgomareobis diagnostikis RonisZiebaTa pirvel jgufs Seadgenen is samuSaoebi, romlebic ar moiTxoven muSa transformatorTan Sexebas, esenia: CamoTvlili kontrolisa da sazomi saSualebebisa da sasignalo mowyobilobebis CvenebaTa kontroli; transformatorebis garegani daTvalierebа.

meore jgufs miekuTvnebian is samuSaoebi, romlebic ar moiTxoven gamorTvebs, magram dakavSirebuli arian transformatoris an mis damxmare mowyobilobebTan SexebasTan. maT miekuTvneba: zeTis sinjis aReba eleqtruli Tvisebebis Sesamowmeblad da qimiuri analizisaTvis an zeTSi gaxsnili airebis qromatografiuli analizisaTvis. Aamave jgufs miekuTvneba transformatoris avzisa da sxva nawilebis vibraciisa da specialuri aparaturiT nawilobrivi ganmuxtvis donis gazomva, amuSavebuli gazuri reledan gazis aReba da sxva.

mesame jgufs miekuTvneba samuSaoebi, romlebic sruldeba gamorTul transformatorze. Eesenia: izolaciis, gragnilebis, magnitogamtaris, maRali Zabvis Semyvanebis, gadamrTveli da damxmare mowyobilobebis mdgomareobis gamocdisa da gansazRvris samuSaoebi. Aam jgufs miekuTvneba agreTve profilaqtikuri samuSaoebis yvela saxeoba, eleqtrotumboebis daTvaliereba, reviziis sxvadasxva saxeebi da sxva.

meoTxe jgufs miekuTvnebian remontSi gamoyvanili transformatoris samuSaoebi. Aam dros swarmoebs calkeuli nawilebis mdgomareobis Sesaxeb sruli analizi remontis moculobis gansazRvrisa da dazustebis mizniT. agreTve ganisazRvreba is sakontrolo operaciebi, rac ganisazRvreba transformatorebis damzadebisa da montaJis dros. amasTanave transformatorebis remontSi gadayvanis saWiroebis Sesaxeb gadawyetileba miiReba diagnostikis pirveli sami jgufis operaciebis Sedegebis safuZvelze.

qvemoT ganvixilavT eqspluataciaSi myofi Zalovani transformatorebis mdgomareobis Semowmebis erTerT xerxs.

### 1.7. sakontrolo - sazomi xelsawyoebis CvenebaTa kontroli da transformatorebis daTvaliereba

teqnikuri eqspluataciis wesebiT dadgenilia transformatoris daTvalierebis aucilebeli perioduloba. Mmudmivi morige personalis arsebobis dros eleqtruli sadgurebisa da qvesadgurebis mTavari da sakuTari moxmarebis transformatorebisa da reaqtorebis daTvaliereba swarmoebs gamorTvis gareSe erTxel dReRamis ganmavlobaSi. xolo danarCeni transformatorebi SeiZleba daTvalierebulni iqnen kviraSi erTjer. transformatorze dayenebuli sazomi xelsawyoebis Cvenebebi, Tu saWiroeba moiTxovs, eleqtrosadguris an energosistemis romelime ubnis datvirTvis reJimis kontrolisaTvis, aRebuli unda iqnes yovel saaTSi an naxevarsaaTSi.

Tu ar aris mudmivi morige personali, maSin transformatoris daTvaliereba swarmoebs gamsvleli brigadis mier TveSi erTxel,xolo aseTi transformatorebis datvirTvis kontroli xorcieldeba weliwadSi orjer, maT Soris erTjer zamTris periodSi datvirTvis maqsimumis dros.

perioduli daTvalierebis dros Semowmebuli unda iqnes faifuris izolatorebis, Semyvanebis safarisa da ganmmuxtvelebis mdgomareoba. gansazRvruli unda iqnes arsebobs Tu ara faifurze CamonaxeTqebi da bzarebi, gaWuWyianebulia Tu ara zedapiri, adgili aqvs Tu ara zeTis gaJonvas SemWidroebebSi. saWiroa davrwmundeT sazomi xelsawyoebis, Termosignalizatorebisa da Termometrebis. zeTmaCveneblebis, gazuri releebis, gamasabolqvi milis membranis mTlianobasa da wesivrulobaSi. agreTve unda Semowmdes safarToebelTan milze avtomaturi wamkveTi sarqvelis mdebareoba, haersaSrobSi indikatoruli silica-gelis, zeTsadenebSi miltuCebis SeerTebisa da SeduRebis nakerebis mdgomareoba.

transformatorze dayenebuli eleqtrosazomi xelsawyoebi jer kidev ar iZlevian misi mdgomareobis Sefasebis saSualebas. isini gvexmarebian droulad gamovavlinoT denisa da Zabvis mixedviT gadatvirTvebi.

teqnikuri eqspluataciis wesebSi, qarxana-damamzadeblis Sesabamis standartebsa da instruqciebSi naCvenebia nominaluri mniSvnelobis zemoT Zabvebisa da denebis zRvrulad dasaSvebi mniSvnelobebi da maTi dasaSvebi xangrZlivoba. magaliTad, amJamad moqmedebaSi myofi 1985 wlamde gamoSvebuli transformatorebisaTvis nominaluri datvirTvis dros xangrZlivad dasaSvebia nominalurs zeviT Zabvis 5 % -iT gadaWarbeba. Mmcire datvirTvis dros (nominaluris araumetes 25 % - s dros) dasaSvebia Zabvis 10 %- iT gadaWarbeba. amdeniTve SeiZleba Zabvis xanmokle (araumetes 6 sT dReRameSi) gadaWarbeba nominaluri datvirTvis dros.

zeTiani transformatorebisaTvis dasaSvebia nominalurs zeviT 5 % - iT gadatvirTva, Tu Zabva nominaluria. Aavariul reJimebSi dasaSvebia denis mixedviT xanmokle gadatvirTvebi cxrilSi 1.2 naCveneb sazRvrebSi.

cxrili 1.2. zeTiani transformatoris dasaSvebi xangrZlivoba denis mixedviT

| gadatvirTva denis mixedviT, % | 30 | 45 | 60 | 75 | 100 |
|---|---|---|---|---|---|
| dasaSvebi xangrZlivoba, wT | 120 | 80 | 45 | 20 | 10 |

100 mva simZlavris CaTvliT axali transformatorebisaTvis dasaSvebi sistematuri da avariuli gadatvirTvebi naCvenebia standartSi ГОСТ 14209-85 Si. masSi adre moqmedi ГОСТ 14209-69 – sagan gansxvavebiT dasaSvebi avariuli gadatvirTvebi daSvebulia wina datvirTvisa da garemo temperaturaze damokidebulebiT. avariuli gadatvirTvebis normebis analogiuri garTulebebi Setanilia 100 mva-ze zeviT simZlavris transformatorebis eqspluataciis axal instruqciebSi. bevr SemTxvevaSi axali instruqciebiT ZvelTan SedarebiT dasaSvebia naklebi gadatvirTvebi.

Zabvis qveS regulirebis mowyobilobebis daTvalierebisas saWiroa yuradReba mieqces amZravi meqanizmisa da marTvis faris maCveneblebze mdebareobis Sesabamisobas. amZravi meqanizmis yvela elementi unda iyos fiqsirebul mdgomareobaSi. Semowmebuli unda iqnes zeTis done kontaqtoris avzSi an safarToeblis Sesabamis nakveTurSi, gansarTebisa da saxSobis SemWidroebebi, zamTris periodSi – amZravis gamaTbobelis mdgomareoba. saWiroa Zabvis qveS regulirebis mowyobilobis gadamr-Tvelis mricxvelis Cvenebis dafiqsireba.

transformatoris perioduli gareSe daTvalierebisas unda Semowmdes masze arsebuli yvela sakontrolo saSualeba, radganac isini afiqsireben saSiSroebis aRZvris SesaZlebloba. magaliTad, transformatorSi zeTis donis daweva dasaSvebze metad mowmobs imas, rom adgili aqvs gadinebebs an Casxmuli iyo arasakmarisi raodenobis zeTi.Ddaweuli zeTis doniT transformatoris Semdgomma muSaobam SeiZleba migviyvanos gazuri reles amuSavebamde, zeTis daCqarebul daZvlebamde an gaciebis sistemis mtyunebamde. xolo Tu gragnilebis izolacia aRmoCnda zeTis donis zeviT, maSin SesaZlebelia haerSi moxdes gadafarva, rac gamoiwvevs gragnilebs Soris mokled SerTvas da seriozul avarias. zeTis donis aweva iwvevs mis gadmoRvras. azotis dacvis mqone transformatorebSi am dros sasunTq sistemaSi warmoiqmneba sacobi, am sistemis muSaoba uaresdeba da SeiZleba amuSavdes gazuri rele an gamosabolqvi milis membrana.

transformatoris TiToeuli daTvalierebis dros saWiroa Semowmdes da Caiweros zeTis temperatura. normebiT dadgenilia zeTis zeda fenebis temperatura. nominaluri datvirTvis dros es temperatura ar unda aRematebodes 95° C zeTis bunebrivi gaciebisa da ventilato-rebiT dabervis dros, 75 ° C –s iZulebiTi dabervis dros da 70 °C - s zeTsacivaris Sesasvlelze zeTis wyliT gaciebis dros. Tu zeTis temperatura aRemateba dasaSvebs, maSin unda gairkves mizezebi da miRebuli iqnes RonisZiebebi uwesivrobis gamosasworeblad. pirvel rigSi unda Semowmdes gaciebis

sistemebis: ventilatorebis, zeTis eleqtro-tumboebis, haerisa da wylis zeTsacivrebis wesivruloba. Tu gaciebis sistemaSi darRvevebi ar aRmoCnda, maSin zeTis temperaturis aweva umravles SemTxvevaSi mowmobs transformatorSi Siga dazianebis arsebobas: mokled SerTuli konturis warmoqmnas, kontaqtur SeerTe-bebSi gardamavali winaRobis gazrdas, izolaciis gajirjvebis Sedegad zeTis arxebis kveTis Semcirebas, arxSi gareSe sagnebis moxvedras da a.S. yvela SemTxvevaSi transformatorebis xangrZlivi muSaoba aweuli temperaturiT dauSvebelia.

maRali Zabvis SemyvanebSi zeTis wnevis dacema umravles SemTxvevaSi ganpirobebulia Semyvanis hermetulobis darRvevis Sedegad. aseTi dazianeba Zalian saSiSia. Tu manometri daziane-bulia, maSin hermetulobis dazianeba droulad ver iqneba SemCneuli, amitom manometrebi regula-rulad unda Semowmdes.

maRalvoltiani Semyvanebis daTvalierebisas yuradReba unda mieqces SemWidroebebSi zeTis gadinebebs, sazomi da Camamiwebeli sade-nebis mTlianobasa da maTi mierTebis saimedobas.

indikatoruli silikageli warmoadgens satransformatoro zeTis danestianebis gansazRvris umartives saSualebas. igi Seisrutavs zeTSi moxvedril nests da iRebs vardisfer Seferilobas, xolo Semdgom iRebs ufro kaSkaSa fers. Aam dros mizan-Sewonilia aviRoT zeTis sinji misi tenianobis uSualod gazomvisaTvis da agreTve Semowmebuli unda iqnas misi sxva Tvisebebic, radgan zogierT SemTxvevaSi indikatoruli silikagelis feris Secvla SeiZleba gamowveuli iyos zeTis intensiuri daZvelebiT.

bunebrivia, rom daTvalierebisas SeiZleba gansazRvruli iqnes transformatoris normaluri muSaobis xelSemSleli sxva darRvevebic. magaliTad, transformatorisa da misi elementebis momatebuli vibracia, gare kontaqturi SeerTebebisa da salteebis damagrebis darRvevebi, raime elementis deformacia, avtomaturi xanZarmqrobi sistemebis dazianeba da sxva.

# 2. შედეგები და მათი განსჯა

## Tavi II.MmaRali Zabvis eleqtromowyobilobebis diagnostikis sistemis meTodologia.

eleqtromowyobilobebis teqnikuri mdgomareobis kontroli, maTi uwesivrobebis gamovlena, aRmofxvra da saeqspluatacio resursebiT uzrunvelyofa miiRweva mowyobilobebis diagnostikis efeqturi meTodebisa da saSualebebis gamoyenebiT.

rTul teqnikur saSualebebs Soris, romlebic eqspluataciis dros moiTxoven diagnostirebas, gansakuTrebul adgils iWeren maRali Zabvis mowyobilobebi, romelTac miekuTvnebian transformatorebic. es mowyobilobebi eqvemdebarebian mZlavri eleqtruli, eleqtromagnituri da Tburi velebis kompleqsur zemoqmedebasa da eleqtrodinamiur datvirTvebs. amasTan dakavSirebiT am eleqtromowyobilobebSi advilad warmoiSveba defeqtebi, uwesivrobebi da mtyunebebi. amitom defeqtebisa da uwesivrobebis Camoyalibebis droulad Setyobinebis mizniTa da mowyobilobebis saeqspluatacio saimedobis SenarCunebisaTvis gamoiyeneba eleqtromowyobilobis kontroli diagnostikis sistemis saxiT.

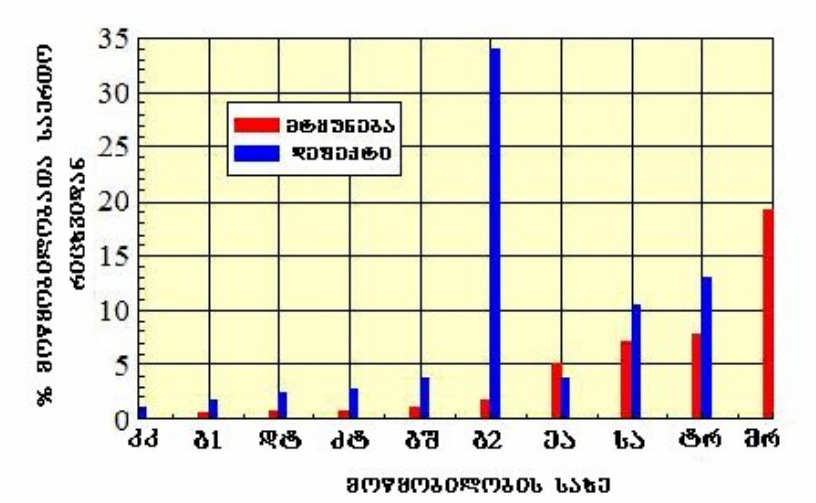
saerTod teqnikuri mowyobilobebisa da maT Soris maRali Zabvis eleqtromowyobilobis diagnostika es aris codnis sfero, romelic moicavs eqspluataciis pirobebSi eleqtromowyobilobebis muSaobis Teorias, teqnikuri mdgomareobis gansazRvris meTodebsa da saSualebebs [63-65]. diagnostika rogorc mecniereba da misi praqtikuli gamoyeneba imyofeba sxvadasxva mecnierebis ganyofilebebis zRvarze. pirvel rigSi es exeba fizikasa da qimias sxvadasxva saxis masalebis (dawyebuli gazisebridan damTavrebuli myari sxeulebiT) Tvisebebis cvlilebisa da qcevis nawilSi da procesebs, romlebic mimdinareobs maTSi sxvadasxva faqtorebis zemoqmedebiT.

diagnostika miekuTvneba aseve maTematikas eqsperimentuli monacemebis statistikuri damuSavebisa da analizis meTodebisa

da rTuli amocanebis gadasawvetad kompiuteruli programebis damuSavebis nawilSi.

rogorc cnobilia maRali Zabvis mowyobilobebi eqvemdebarebian defeqtebisa da uwesivrobebis Camoyalibebis maRal risks da aqvT sakmaod maRali avariuli SemTxvevebi. dReisaTvis gamoyenebuli uwesivrobis gamovlenisa da profilaqtikis meTodebi saSualebas iZlevian mxolod ramdenadme SevamciroT mtyunebebi.

nax.2.1-ze warmodgenilia saqarTvelos saxelmwifo eleqtrosistemaSi 110-500 kv mowyobilobebis saxeobebis mixedviT mtyunebebis, uwesivrobisa da defeqtebis gamovlenis jamuri ganawileba qvesadgurebSi, Ria da daxurul gamanawilebel mowyobilobebSi.

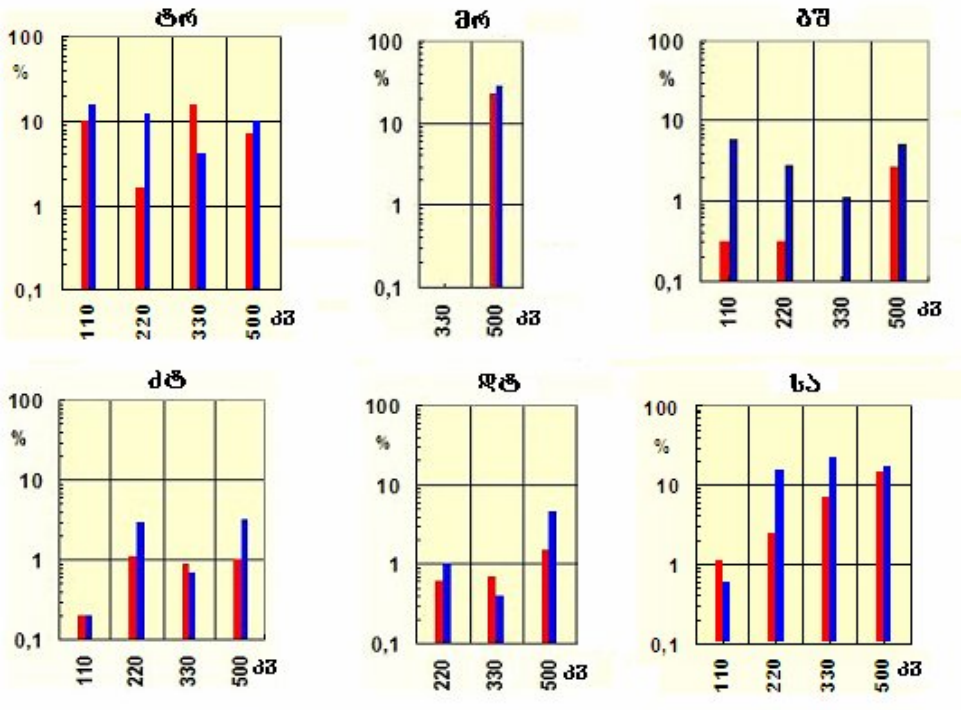



nax.2.1. mtyunebaTa da gamovleni li defeqtebis ganawileba mowyobilobaTa saxeobebis mixedviT: kk- kavSiris kondensatori; g1 – gamTiSebi; dt, Zt – denisa da Zabvis transformatorebi; gS- gadaZabvebis SemzRudveli; g2- ganmmuxtvelebi; ea, sa – elgazuri da sahaero amomrTvelebi; tr- Zalovani transformatorebi; mr - maSuntirebeli reaqtorebi.

nax.2.2-ze warmodgenilia sxvadasxva klasis izolaciis mqone calkeuli saxis mowyobilobebis mtyunebaTa da gamovleni li defeqtebis ganawileba. mtyunebaTa da gamovleni li defeqtebis ganawileba miekuTvneba mowyobilobaTa Sesabamis tips. aq warmodgenilia sami wlis ganmavlobaSi daaxloebiT 1500 erTeuli mowyobilobis eqspluataciis Sedegebi. rogorc aq warmodgeni li

diagramebidan Cans, gamovlenili defeqtebis raodenoba ZiriTadad aRemateba mtyunebaTa ricxvs. gamoyenebuli rom ar yofiliyo mowyobilobis diagnostireba, maSin mosalodneli iyo mtyunebaTa ricxvis kidev 10-20 % -iT gazrda [66].

warmodgenili ganawilebis analizidan gamomdinare SesaZlebelia avRniSnoT, rom mowyobilobis izolaciis klasis zrdasTan erTad arsebobs mtyunebaTa zrdis tendencia. gamovlenili uwesivrobebisa da defeqtebis didi nawili pirvel rigSi miekuTvneba eqspluataciaSi Seyvanil axali tipis mowyobilobebs, rac gamowveulia maTi damzadebis xarisxiT.




nax.2.2. erTi tipis sxvadasxva klasis izolaciis mqone mowyobilobebis mtyunebaTa da gamovlenili defeqtebis ganawilebas.

diagnostirebis umTavresi amocanebia:

- eleqtromowyobilobis teqnikuri mdgomareobis gansazRvra cvalebadi eqspluataciis zemoqmedebis pirobebSi;
- defeqtis saSiSroebis saxisa da xarisxis gamovlena;
- narCeni resursis an muSaobis xangrZlivobis vadis prognozireba.

es amocanebi sakmaod farToa da mowyobilobis saxeobisa da misi eleqtromomaragebis regionSi adgilis mixedviT moiTxoven konkretizacias. diagnostikis saxeobis Sesaxeb gadawyvetilebis miReba dafuZnebulia teqnikoekonomiur dasabuTebaze. aseTi gadawyvetileba sufTa momxmarebluri xasiaTisaa. erTi mxriv ismeba diagnostikis parametrebisa da maTi funqcionaluri kavSirebis kompleqsebis gamoyenebiT mowyobilobis obieqturi mdgomareobis Sefasebis amocana, xolo meore mxriv moiTxoveba materialuri resursebis gamoyenebis SezRudva, anu ekonomika, romelic arsebiTad amcirebs diagnostirebis amocanebs, ramac SeiZleba ver uzrunvelyos mowyobilobis mdgomareobis obieqturi gansazRvra.

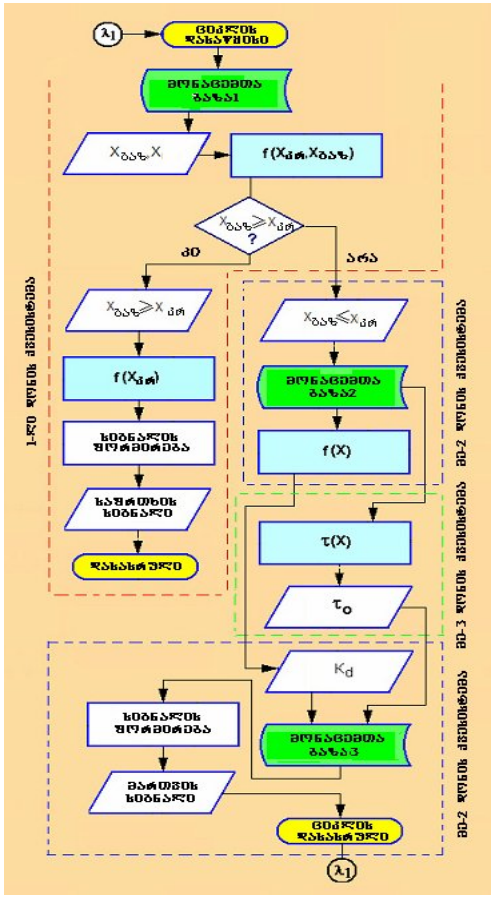
teqnikuri diagnostikis sistema warmoadgens obieqtebisa da saSualebebis erTobliobas, romelic saWiroa normatiul-teqnikuri dokumentaciis wesebiT dadgenili diagnostirebis (kontrolis) CatarebisaTvis.

diagnostikis sistemis struqturuli sqema mravaldoniania warmodgenilia misi sami funqcionaruli nawiliT (nax 2.3).

nax.2.3-ze mocemul algoriTmis struqturul sqemaze $f(X_{kr},X_{gaz})$ aris parametrebis gardaqmnisa da analizis bloki; $f(X_{kr})$ – teqnikuri mdgomareobis bloki; $f(X)$ – dinamiuri maxasiaTeblebisa da ganviTarebadi defeqtebis modelebis bloki; $\tau(X)$ – narCeni resursebis modelebis bloki; monacemTa bazebi 1, 2 3 – diagnostikuri parametrebis monacemTa bazebia.

struqturul sqemaze warmodgenili pirveli donis qvesistema uzrunvelyofs:

- informaciuli parametrebis Senaxvas;
- diagnostikuri parametrebis gazomvas;
- gazomili diagnostikuri parametrebis damuSavebas, maT norma-lizebul saxeSi warmodgenasa da damuSavebuli gazomvis Sedegebis monacemTa bazaSi gadacemas.



nax.2.3.maRali Zabvis eleqtromowyobilobis diagnostirebis algoriTmis struqturuli sqema.

-gazomili parametrebis mniSvnelobebis normirebul mniSvnelobebTan Sesabamisobis gansazRvrasa da obieqtis teqnikuri mdgomareobis normatiul - teqnikuri dokumentaciis moTxovnebTan Sesabamisobaze daskvnis Fformirebas;

-gazomili parametrebis mniSvnelobebis normirebul mniSvnelobebze gadaWarbebis SemTxvevaSi obieqtis eqpluataciis safrTxis Sesaxeb signalis formireba;

-gadamwodebis mgrZnobiarobis cvlilebis, gazomvisa da sinqronizaciis xangrZlivobisa da periodulobis Sesaxeb brZanebis signa-lis miReba.

meore donis qvesistema uzrunvelyofs:

-ganviTarebadi defeqtebis saxeobisa da adgilis gansazRvras;

-warmoebuli da dinamiuri diagnostikuri maxasiaTeblebis gaangariSe-bas;

- retrospeqtuli diagnostikuri parametrebis gansazRvras;

- ganviTarebadi defeqtebis safrTxis xarisxis gansaRvras;

- pirveli donis qvesistemidan miRebuli brZanebis mixedviT muSaobis algoriTmis cvlilebas;

- gaangariSebisa da analizis Sedegebis monacemTa bazaSi gadacemas;

- obieqtis gacivebis sistemis muSaobis reJimis cvlilebis Sesaxeb signalis formireba.

mesame donis qvesistema uzrunvelyofs obieqtis narCeni resursis Sefasebas.

teqnikuri diagnostikis ZiriTadi amocanebidan gamomdinare, pirveladi aqtiT gansazRvruli unda iyos teqnikuri mdgomareobis saxe. uwesivrobisa da defeqtis faqtis dadgenis Semdeg moZebuli unda iyos dazianebis adgili, saxe, misgan gamowveuli safrTxe da gansazRvruli unda iqnes uwesivrobis mizezi.

obieqtze SeiZleba warmoiqmnas da ganviTardes defeqtebis cxadi da aracxadi saxeebi, xolo diagnostireba SeiZleba mxolod cxadi defeqtebisa. aracxadi defeqtebis kategorias miekuTvneba is defeqtebi, romlebic SemCneuli ver iqnen misi SemCnevis meTodebisa da saSualebebis ar arsebobis gamo.

eleqtromowyobilobebis elementebisa da detalebis teqnikuri mdgomareobis, maT funqcionirebaSi yvela saxis darRvevebis gansazR-vras xdeba diagnostikuri parametrebis gamoyenebiT.

diagnostikuri parametrebi iyofa sam tipad:

- informaciuli saxis parametrebi, romlebic warmoadgenen obieqtis maxasiaTeblebs, $X_{inf}$;

- obieqtis (kvanZebis) elementebis mimdinare teqnikuri maxasiaTeblebis parametrebi, $X_i$;

- parametrebi, romlebic warmoadgenen ramdenime parametris warmoebuls, $X_{war}$.

informaciuli saxis ($X_{inf}$) parametrebs miekuTvnebian:

- obieqtis tipi;

- obieqtis eqspluataciaSi Seyvanis dro da eqspluataciis periodi;

- obieqtze Catarebuli saremonto samuSaoebi;

- obieqtis arasaStato situaciebSi yofnis dro;

- obieqtis teqnikuri maxasiaTeblebi, romlebic miRebulia qarxana-damamzadebelSi an eqspluataciaSi Seyvanisas Catarebuli gamocdebis dros;

- diagnostikuri parametrebis ($X_{kr}$) normirebuli mniSvnelobebi;

- $X_i$ obieqtis teqnikuri maxasiaTeblebi, romlebic warmodgenilia drois mixedviT absoluturi – $X_i(t)$ mniSvnelobiT an maTi warmoebulis ($dx/dt$) saxiT.

diagnostikuri parametrebis ($X_{kr}$) normirebuli mniSvnelobebi gamoiyeneba gazomviT miRebul diagnostikur parametrebTan maTi mniSvnelobebis SepirapirebisaTvis.

informaciuli saxis sxva parametrebi upiratesad gamoiyeneba im SemTx-vevebSi, roca gazomil diagnostikur parametrebs aqvT $X_{kr}$ normirebul mniSvnelobebTan miaxloebuli mniSvnelobebi da dinamiur maxasiaTeblebs ($dX_i/dt$) gaaCniaT didi mniSvnelobebi.

diagnostikur parametrebs, romlebic warmoadgenen $X_i$ obieqtis elementebis (kvanZebis) mimdinare teqnikur maxasiaTeblebs, miekuTvnebian mimdinare momentSi gazomili parametrebi. es parametrebi mowyobilobis saxeobebis mixedviT erTmaneTisagan gansxvavdebian. amasTanave mTeli rigi obieqtebisa kontrolisaTvis gamoiyeneben parametrebis erTsa da imave saxes. es parametrebi erTmaneTisagan gansxvavdebian mxolod sxvadasxva normirebuli mniSvnelobebiT.

gasazomi diagnostikuri parametrebis raodenoba damokidebulia mowyobilobis saxeobaze da diagnostirebis meTodebis ganviTarebis xarisxze. ase magaliTad, gasazomi diagnostikuri parametrebis ricxvi Zalovan transformatorebsa da maSuntirebel reaqtorebSi aRwevs 38; zeTian amomrTvelebSi – 29; elgazur amomrTvelebSi – 25; gadaZabvebis SemzRudvelebsa da gamTiSebSi –

10; ganmamxoloeblebSi (amZraviT) – 14; zeTiT Sevsebul sazom transformatorebsa da kavSiris kondensatorebSi – 9.

teqnikuri mdgomareobis ufro obieqturi SefasebisaTvis mizanSewonilia gamoyenebul iqnas diagnostikuri parametrebis kompleqsi. amasTanave am kompleqsis gamoyeneba mTeli moculobiT ZiriTadad damokidebulia sakontrolo obieqtis Zabvis klassa da Zalovani mowyobi-lobebis, saxeldobr, transformatorebisa da reaqtorebis simZlavreze. Tu 330-500 kv mowyobilobebisaTvis parametrebis naCvenebi kompleqsi srulad misaRebia, maSin 110 kv mowyobilobebisaTvis teqniko- ekonomiuri araefeqturobis niSniTes maxasiaTeblebi SeiZleba iyos Warbi.

rogorc zemoT moyvanili diagnostikuri parametrebis saxeebidan Cans, patrametrebis ricxvi da saxe damokidebulia sakontrolo obieq-tis saxeze, mxolod parametrebis SezRuduli raodenoba warmoadgens nebismieri obieqtis saerTo saxes.

diagnostikur parametrebs, romlebic warmoadgenen ramdenime parametris warmoebuls, pirvel rigSi miekuTvnebian iseTi saangariSo maxasiaTeblebi, rogoricaa satransformatoro zeTSi gaxsnili airebis kritikuli mniSvnelobebis Semcvelobis fardobebi, magaliTad, $CH_4/H_2$; $C_2H_2/C_2H_4$; $CO_2/CO$; $C_2H_4/C_2H_6$ da sxva; nebismieri K datvirTvisas (datvir-Tvis denis fardoba nominalur denTan) transformatoris yvelaze ufro gaxurebuli wertilis maqsimaluri temperatura tolia:

$$\theta_h = \theta_a + \Delta\theta_{hr} [ (1+RK_2)/(1+R)] + H_{qr}K^y$$

sadac $\theta_a$ – aris gamaciebeli garemos temperatura; $\theta_{hr}$ – yvelaze ufro gaxurebul wertilSi temperaturis aweva; R-datvirTvis danakargebis fardoba uqmi svlis danakargebTan, romelic aiReba 5-6 farglebSi; $H_{qr}$ – yvelaze ufro gaxurebul wertilSi temperaturis gradienti, romelic gaciebis sistemis mixedviT aiReba 22-29 farglebSi. y – aris gragnilis xarisxis maCvenebeli da aiReba 1,6 toli.

celulozis (qaRaldis, muyaos) izolaciis fardobiTi cveTis siCqare tolia:

$$V = 2^{(\Theta h - 98)/6}$$

nawilobrivi ganmuxtvis saSualo deni $I = (\Sigma q_i n_i)/T$ da sxva.

warmoebul diagnostikur parametrebs miekuTvnebian aseve $x_i(t)$ dinamiuri maxasiaTeblebi da maTi warmoebulebi $(dx_i/dt)$. dinamiuri parametri $x_i(t)$ SeiZleba iyos mimdinare, roca ganisazRvreba fardoba drois mezobel momentebs Soris da SeiZleba iyos ganzogadoebuli, roca ganisazRvreba fardoba drois arCeul intervalebSi.

nebismieri obieqtis teqnikuri mdgomareoba SeiZleba dadgenili iqnes erTjeradi da mravaljeradi diagnostirebis dros. mravali elementisagan Sedgenili maRali Zabvis aparaturis erTjeradi diagnostirebis dros teqnikuri mdgomareobis obieqturi Sefasebis albaToba mcirea. maSasadame, mxolod SemTxveviT SeiZleba SevamCnioT defeqti erTjeradi diagnostirebis dros. teqnikuri mdgomareobis saimedo da obieqturi Sefasebis albaToba izrdeba kontrolis ricxvis zrdasTan erTad. es garemoeba warmoadgens garkveuli periodulobiT mravaljeradi diagnostirebis SemoRebis, anu diagnostikuri parametrebis monitoringis safuZvels.

diagnostikuri parametrebis gansazRvraSi mniSvnelovan moments warmoadgens maTi registraciis perioduloba. registraciis perioduloba damokidebuli unda iyos obieqtis nebismier sakontrolo kvanZsa da detalSi defeqtebis warmoqmnisa da ganviTarebis siCqareze. mowyobilobis normalur reJimSi muSaobis dros daZvelebis procesebi Zalian nela mimdinareobs. mowyobilobis dadgenili muSaobis xangrZlivoba gaTvlilia swored am procesebis moqmedebidan gamomdinare. muSaobis es vada dadgenilia mowyobilobis yvelaze ufro kritikuli kvanZebis daZvelebidan gamomdinare. Tu miviRebT, rom muSaobis xangrZlivoba 40 welia, maSin daZvelebis xarisxis gamosavlenad sakmarisia daaxloebiT 3 Tvis perioduloba. defeqtebis gamovlenis dros daZvelebis procesi SeiZleba mniSvnelovnad daCqardes. praqtikaSi gamovlenili defeqtebis

ricxvidan yvelaze ufro swrafad ganviTarebad defeqtebs warmoadgens eleqtruli ganmuxtvis (nawilob-rivi ganmuxtvis) defeqtebi. am procesebis kvlevis Sedegebi 220 kv zeTSevsebuli Semyva-nebisa da 500 kv denis sazomi transformatorebis izolaciaSi gviCveneben, rom eleqtruli izolaciis mdgomareobis damaxasiaTebeli diagnostikuri parametrebis registraciis minimalurma periodulobam SeiZleba Seadginos 2 saaTi.

arsebobs dacvis mowyobilobidan gamomavali diskretuli signalebi, romlebic zemoqmedeben gamorTvaze. maTi moqmedebis momenti aseve unda mivakuTvnoT diagnostikur parametrebs, romlebic miewodebian diagnostirebis lokaluri sistemis servers. aseTi signalebis periodulobam SeiZleba Seadginos 1-2 miliwami.

arsebobs aseve diagnostikuri parametrebi, romlebic ganisazRvrebian mxolod warmoqmnis faqtiT. aseT parametrebs miekuTvnebian, magaliTad, gazuri reles amuSavebisa da wnevis davardnis mowyobilobis signalebi, gadaZabvebis amplituda da ZiriTadi sixSire, ganmmuxtvelis (gadaZabvebis SemzRudveli) amuSavebisas an gamTiSebisa da amomrTvelebis komutaciisas, Zabvis amplituda da ZiriTadi sixSire, mokled SerTvis SemTxvevaSi denis amplituda da ZiriTadi sixSire. am SemTxvevebSi signalebis registracia swarmoebs sakuTriv am signalebidan aRZruli movlenebiT.

dReisaTvis arsebobs SesaZlebloba teqnikuri saSualebebiT avtomaturad gavzomoT mimdinare diagnostikuri parametrebis ZiriTadi nawili muSa Zabvis qveS anu on-line reJimSi. diagnostireba swarmoebs ciklur formaSi. TiToeuli cikli moicavs parametrebis mTeli kompleqsis gazomvas, risTvisac aucilebelia parametrebis erTxel mainc registracia.

nax.2.3-ze mocemuli diagnostirebis algoriTmis struqturuli sqemis diagnostirebis sistemis safuZvels ESeadgenen analizuri modelebi.

mowyobilobis diagnostirebis dros defeqtis warmoqmnisas mimdinare movlenaTa urTierTqmedebis codna mniSvnelovani

pirobaa sistemisa da mTlianad obieqtis teqnikuri mdgomareobis modelebis Sesaqmnelad movlenaTa logikuri jaWvis gansazRvrisaTvis. maSasadame, sakontrolo obieqtis parametrebis gazomvis Sedegebis analizisas movlenaTa sqemis ageba warmoadgens diagnostikis meTodikis Semadgenel nawils.

diagnostirebis algoriTmis ZiriTad nawils warmoadgens modeli [67-68]. obieqtisa da obieqtSi momdinare movlenebis srul aRwerazea damokidebuli diagnostirebis Sedegebis saimedoba. maRali Zabvis mowyobilobis struqtura zogadad SeiZleba SevadaroT myari fizikuri sxeulis struqturas, romelsac gaaCnia makroskopuli araerTgvrovneba. maTSi saerToa mravali elementis arseboba, romelTa Tvisebebis cvlilebam an romelime maTganis gamoricxvam SeiZleba migviyvanos obieqtis Tvisebebis cvlilebasTan da zRvrul mdgomareobaSi SeiZleba migviyvanos obieqtis funqcionirebis SewyvetasTan. maT Soris saerToa aseve gareSe saeqspluatacio faqtorebis zegavleniT maTi Tvisebebis an mdgomareobis Secvla.

modeli Sedgeba mTeli rigi nawilebisagan (blokebisagan), romelTac erTmaneTTan gaaCniaT funqcionaluri kavSirebi. rogorc wesi aseTi nawilebi ertmanetisagan izolirebulad ar ganixilebian. maTi jamuri wvlili mTlianad modelis funqcionirebaSi ganpirobebulia nawilebs Soris urTierTqmedebiT. mowyobilobis diagnostirebisas mniSvnelvania vicodeT movlenaTa Tanmimdevroba, romelTac SeuZliaT migviyvanon detalebisa da kvanZebis mtyunebamde. amdros mxedvelobaSi miiReba is fizikuri procesebi, romlebic gansazRvraven masalebisa da konstruqciis degradacias [69-70]. mizanSewonilia Taviseburi e.w. `mtyunebaTa xis" an `movlenaTa xis" ageba, romelic warmoadgens imirobaTa aRZvris Tanmimdevrobas, romelsac mihyavs mTlianad obieqti an misi sistema mtyunebamde. maSasadame, modelebSi maTematikurad aRiwereba obieqtSi mimdinare fizikuri procesebi [71].

teqnikuri mdgomareobis ($X_{kp}$) modeli warmoadgens diagnostikis sistemis pirveli donis qvesistemis ZiriTad elements. es aris mTlianad obieqtis, obieqtis sistemis an kvanZebis teqnikuri mdgomareobis modeli da pasuxobs kiTxvaze: aris Tu ara defeqti?, anu gvaqvs Tu ara gazomili diagnostikuri parametrebis iseTi mniSvnerlobebi, romlebic aRematebian normirebul mniSvnelobebs. teqnikuri mdgomareobis modelSi aris ramdenime modeli, romlebic miekuTvnebian obieqtis sistemebs, magaliTad, eleqtrosaizolacio da gacivebis sistemebi da sxva.

teqnikuri mdgomareobis modeli warmoadgens mTlianad obieqtis, obieqtis sistemis an kvanZis aRweras ramdenime mdgomareobaSi:

- kvanZis, obieqtis sistemis an mTlianad obieqtisa wesivrul mdgomareobaSi;

- detals, kvanZs, obieqtis sistemas aqvs defeqti, romelic mocemul momentSi ar warmoadgens safrTxes eqspluataciisaTvis, magram mivya-varT obieqtis funqcionirebis SezRudvasTan;

- kvanZs, obieqtis sistemas an mTlianad obieqts aqvs defeqti, romelic mocemul momentSi warmoadgens safrTxes obieqtis eqspluataciisaTvis da avariis Tavidan asacileblad moiTxovs zomebis miRebas.

diagnostikis sistemis mniSvnelovani elementia defeqtebis ganviTarebis xasiaTis gansazRvra dawyebuli maTi warmoqmnis stadiidan am defeqtebis aRmweri diagnostikuri parametrebis normirebuli mniSvnelobebis miRwevamde. ganviTarebadi defeqtebis modeli anu deferqtebis safrTxis xarisxis defeqti $f(X,\tau)$ warmoadgens defeqtebis safrTxis donis $K_d$ funqcias, romelic Tavis mxriv ganisazRvreba statikuri $X_{cT}=X_i/X_{kr.i}$ da dinamiuri $X_{din_i} = dX_i/dt$ an $X_{din_i} = (X_{i2}-X_{i1})/\Delta t$. safrTxis done $K_d$ ganisazRvreba $X_{st}$ da $X_{din_i}$ parametrebis maqsimaluri mniSvnelobebiT.

$X_i$ diagnostikuri parametrebis gazomvis Semdeg warmoebs iseTi $X_i$ da $X_{kri}$ mniSvnelobebis Sepirapireba iseTi diagnostikuri

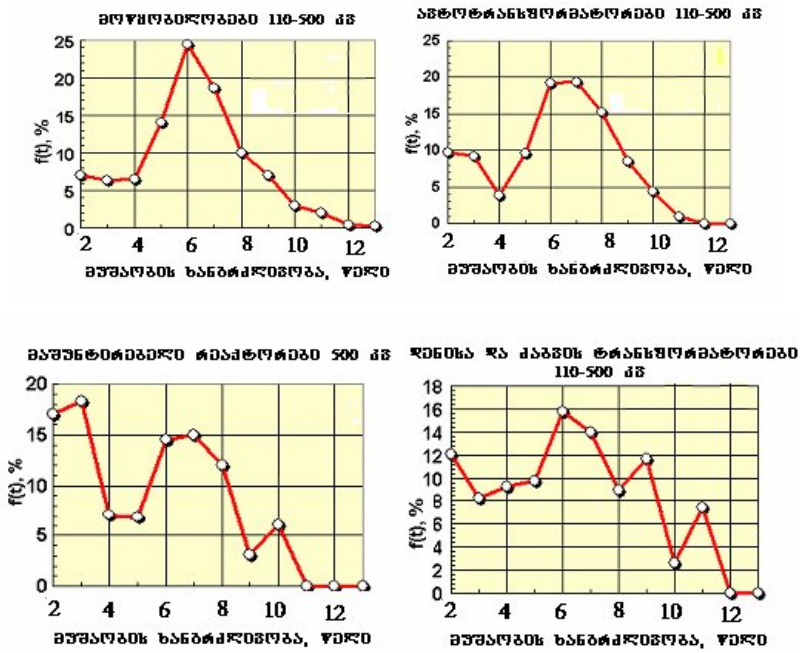
parametrebis moZiebis mizniT, romelTa mniSvnelobebi tolia an aRematebian Sesabamisi $X_{kri}$ parametrebis mniSvnelobebs.

Xi moZebnis dros, romlis mniSvneloba tolia an aRemateba Sesabamisi $X_{kri}$ –is mniSvnelobas, formirdeba signali `uwesivro mdgomareoba" da diagnostireba mTavrdeba. Xi –is ar arsebobisas, romlis mniSvneloba tolia an aRemateba Sesabamisi $X_{kri}$ –is mniSvnelobas, Xi –is gazomili parametrebi gadaecema monacemTa bazas 2 da Semdeg ganviTarebadi defeqtis safrTxis xarisxis $K_d$ gansazRvris mizniT swarmoebs maTi analizi $X_{kr}$ normirebuli mniSvnelobebis gamoyenebiT. $K_d$ – s dadgenili mniSvnelobebis Sesabamisad formirdeba marTvis signali da diagnostirebis cikli mTavrdeba. diagnostikuri ciklis damTavrebis Semdeg diagnostikuri parametrebis gazomvis dadgenili periodulobis Sesabamisad gadaecema brZaneba gazomvis axali ciklis dasawyebad.

narCeni resursis modeli dafuZnebulia narCeni resursis diagnos-tikur parametrebsa da maT warmoebulze funqcionaluri damokide-bulebis gamoyenebaze. am modelis sawyisi monacemebia $X_{st}$ da $X_{dini}$ mniSvnelobebi, romlebic gansazRvruli iyo f(X) modelSi da Seyvanili $K_d$ blokSi, xolo Semdeg – monacemTa bazaSi $3.\tau$ (X) damokidebulebis analizi saSualebas iZleva miviRoT mniSvneloba, romelic warmoadgens obieqtis narCen resurss. undaAaRiniSnos, rom gamovlenili defeqtebis Seswo-rebas mivyavarT diagnostikuri parametrebis mniSvnelobebis cvlilebasTan da Sesabamisad narCeni resursis mniSvnelobis cvlilebasTan.

narCeni resursis SefasebisaTvis gamoiyeneba maTematikur – statistikuri meTodebi. Tu ganvixilavT nax.2.4-ze warmodgenil maRali Zabvis mowyobilobis mtyunebaTa simkvrivis ganawilebis eqsperimentul monacemebs, advilad davinaxavT, rom maRali Zabvis mowyobilobebis mtyunebaTa droiTi ganawilebis funqciebs ar gaaCniaT statistikuri mdgradoba da erTgvarovneba. mtyunebaTa funqciebi $f(\tau)$ gviCveneben, rom isini ar warmoadgenen movlenaTa

erTobliobis anarekls da maT gamoyenebas mivyavarT narCeni resursis gansazRvris dabal saimedobamde. am SemTxvvaSi iyeneben albaTur - stastistikur modelebs




nax.2.4. maRali Zabvis mowyobilobebis mtyunebaTa ganawilebis simkvrive.

eqsperimentuli gamokvlevebis Sedegebze dayrdnobiT, mowyobilobis daZvelebis, cveTis funqcia SeiZleba warmovad-ginoT Semdegi saxiT:

$$A\ (t) = A_t = A[1-(t/t_{res})^{\alpha}] \qquad (2.1)$$

sadac: $t_{res}$ –obieqtis resursia; $\alpha$ – mimdinare drois fardoba obieqtis resursTan.

defeqtis warmoqmnas $t_{def}$ momentSi mivyavarT mtyunebebis mimarT gamZleobis SemcirebasTan, rac gamoixateba $A_t$ mniSvnelobis SemcirebiT $\Delta A$ sididiT. maSin es funqcia intervalSi t=0 dan t= $t_{def}$ SeiZleba warmovad-ginoT Semdegi saxiT:

$$A_t = A[1-(t/t_{res})^{\alpha}]$$

intervalSi t= $t_{def}$ –dan t= $t_{res}$ -mde

$$A_t = A[1-(t'_{res}/t_{res})^{\alpha}] - \Delta A \qquad (2.2)$$

defeqtebis warmoqmnisas, romelic ar aRmoifxvreba Semdgomi eqsplua-taciis dros, daZveleba da mtyunebebis mimarT gamZleoba aRiwereba (2.2) damokidebulebiT, romlis maCvenebels $\alpha$-s eqneba defeqtis safrTxis xarisxze damokidebuli mniSvneloba. $t'_{res}$ moments Seesabameba obieqtis mtyuneba, e.i. $t'_{res} = t_{mty.}$ maSasadame, (2.2) damokidebulebidan miviRebT:

$$A_t = A[1-(t_{mty}/t_{res})^{\alpha}] - \Delta A = 0 \qquad (2.3)$$

anu, roca $A_t = 0$, maSin $t_{mtyun} = t_{resurs} \cdot \sqrt[\alpha]{1-\Delta A}$ (2.4)

maSin narCeni resursi $\Delta t_{res}$ toli iqneba

$$\Delta t_{resurs} = t_{res} - \sqrt[\alpha]{1-\Delta A} - t_{def} \qquad (2.5)$$

aq narCeni resursi ganisaZRvreba rogorc deterministuli funqcia. magram sinamdvileSi mtyunebaTa mimarT gamZleobis (an cveTis) funq-cias aqvs albaTobiTi xasiaTi. Tu cnobilia sakontrolo mowyo-bilobis mtyunebaTa (an daZvelebis) ganawilebis kanoni, maSin MmTeli rigi kompleqsebis daSvebebiT, statistikis maTematikuri aparatis gamoyenebiT SeiZleba SevafasoT SemTxveviTi mtyunebis gamovlenis albaToba. amave dros maRali Zabvis mowyobilobebis mtyunebaTa ganawilebis funqciis f(t) eqsperimentaluri damokidebulebani mowmoben mtyunebaTa rTul funqciebs, romlebic aRweren `daZvelebis" ramdenime sxvadasxvagvar funqciebs, rac iZleva saSualebas ganawilebis parametrebis misaRebad da saimedobis kriteriumebis gansazRvrisaTvis gamoviyenoT statistikis klasikuri meTodebi.

narCeni resursis Sefasebis ganxiluli principi SeiZleba realizebuli iqnes defeqtis TiToeuli saxisaTvis $\Delta A$ –s Sesabamisi mniSvnelobebis dasabuTebiT, romlebic gamowveulia sxvadasxva fizikuri procesebiT. $\Delta A$ –s mniSvneloba defeqtis saxisa da ganviTarebadi defeqtis safrTxis xarisxis $K_d$ sakmaod rTuli funqciaa. igi damokidebulia aseve sakontrolo obieqtis saxeze. es mniSvnelobebi meTodis gamoyenebis pirvel stadiaze ganisazRvrebian eqsperimentis gziT da azusteben im fizikuri procesebis analizis Sedegebis safuZvelze, romlebic

warmoqmnian defeqtebs. am analizis dros defeqtis mtyunebaSi gadasvlis albaTobis gansazRvrisaTvis statistikuri meTodebis gamoyeneba metad efeqturia.

unda aRiniSnos,rom $f(X_{kr}, X_{gaz})$ parametrebis gardaqmnis, teqni-kuri mdgomareobis $f(X_{kr})$, dinamiuri maxasiaTeblebis da ganviTarebadi defeqtebis $f(X)$,aseve narCeni resursis $\tau(X)$ –is analizis modelebi arian diagnostikis sistemis nawili, romlebic asruleben yvela moqmedebas diagnostikuri parametrebis $(X_i)$ monitoringis yvela reJimSi. amasTan dakavSirebiT amocanebis modelebSi gadawyveta unda swarmoebdes gazomvis TiToeul ciklSi $(X_{gaz})$ da diagnostikis aseTi sistemis realizacia SesaZlebelia mxolod kompiuterebis intensiuri gamoyenebis SemTxvevaSi Sesabamisi programuli uzrunvelyofiT.

# Tavi III. Zaluri transformatorebis maTematikuri modelebi

## 3.1. zogadi cnobebi

maTematikuri modelireba warmoadgens adamianis mier gare samyaros movlenebis Secnobis erT-erT ZiriTad instruments. igi aris realuri obieqtis, procesis an sistemis Seswavlis saSualeba maTi maTematikuri modeliT Secvlis gziT, romelic ufro mosaxerxebelia gamomTvleli manqanis gamoyenebiT eqsperimentuli kvlevebis Catarebisas. maTematikuri modelirebis qveS igulisxmeba Sesaswavli movlenis ZiriTadi kanonzomierebani da kavSirebi. es SeiZleba iyos formulebi an gantolebebi, wesebis an SeTanxmebebis krebuli gamosaxuli maTematikuri formiT.

maTematikuri modeli es aris realuri obieqtis, procesis an sistemis miaxloebiTi warmodgena gamosaxuli maTematikuri terminebiT, romelic inarCunebs originalis Tvisebebs. es modelebi logikur-maTematikuri konstruqciebis daxmarebiT aRweren obieqtis, procesis an sistemis ZiriTad Tvisebebs, maT parametrebs, Sida da gare kavSirebs.

maTematikuri modelireba samecniero-teqnikuri progresis ganuyofeli nawilia. Ees aris meTodologia, romelic ar cvlis samecniero disciplinebs, ar uwevs maT konkurencias, magram monawileobs yvela sferoSi mimdinare SemoqmedebiT kvlevebSi. uZvelesi droidan meqanikaSi, fizikaSi da sxva zust sabunebismetyvelo mecnierebebSi Sesaswavli movlenebis aRwerisaTvis gamoyenebulia maTematikuri modelebi.

maTematikuri modelirebis farTo gamoyeneba saSualebas iZleva aiwios Teoriuli gamokvlevebis saerTo done, Catardes isini eqsperimentalur gamokvlevebTan mWidro kavSirSi. maTematikuri modelireba SeiZleba ganixilebodes rogorc Semecnebis, konstruirebis, proeqtirebis axali meTodi, romelic Tavis TavSi Seicavs, rogorc Teoriis aseve eqsperimentis dadebiT mxareebs [72].

eleqtrodanadgarebis maTematikuri modelebis Seqmna da Seswavla iZleva eleqtrodanadgarebis kvlevis did perspeqtivebs.

eleqtroteqnikur sferoSi mimdinare samecniero-kvleviT samuSaoebSi kompiuteris farTod gamoyenebam aucilebeli gaxada maTematikur modelirebasTan erTad eleqtruli wredebis Teoriis sferoSi axali Teoriuli midgomebis damuSaveba da miRebuli Sedegebis WeSmaritebis Sefaseba.

induqciurad dakavSirebuli wredebis modelirebis amocana DdReisaTvis aqtualurad iTvleba. aseTi saxis wredebSi mimdinare fizikuri procesebis Sesabamisi maTematikuri modelebis Sesadgenad saWiro gaxda axali aTvlis sistemis SemoReba. adekvaturi modelirebis amocana didi xania aRelvebs swavlul eleqtroteqnikosebs, razec metyvelebs eleqtroteqni-kosTa saerTaSoriso komisiis kongresze gamarTuli diskusiebi.

induqciurad dakavSirebuli koWebisagan Sedgeba iseTi energetikuli danadgari, rogoricaa Zaluri transformatori, romelic fizikuri procesebis TvalsazrisiT xasiaTdeba rogorc energiis mimRebis, aseve energiis wyaros TaviseburebebiT.

rogorc erTfaza aseve samfaza transformatorebisaTvis maTematikuri modelebisa da Sesabamisi programebis Sedgenisas optimaluri geometriuli da eleqtruli parametrebis gansazRvrisaTvis udidesi mniSvneloba eniWeba. maT safuZvelze SeiZleba Seiqmnas energoefeqturi gamanawilebeli transformatorebi uqmi svlisa da datvirTvis mcire danakargebiT.

## 3.2 erTfaza transformatoris maTematikuri modeli

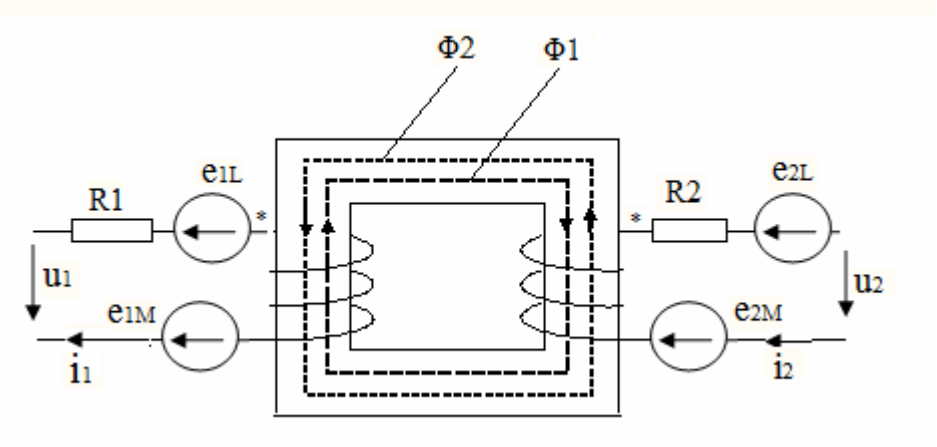
galvanurad dakavSirebuli wredebisaTvis kirxhofis meore kanoniT wonasworobis gantolebaTa sistemis Sedgena kargad aris cnobili, magram induqciurad dakvSirebuli wredebisaTvis kirxhofis gantolebaTa sistemis Sedgenis sakiTxi problemuri sakiTxia.

induqciurad dakavSirebuli wredebis gantolebebis sworad dasawerad aucilebelia erTsaxela momWerebis moniSvna. radganac transformatori warmoadgens induqciurad dakavSirebul wreds. misi gantolebebis dawerisas unda gvaxsovdes induqciurad

dakavSirebuli wredebis Tviseba, kerZod Tu erTi maTganis erTsaxela momWerSi Sedis mzardi deni, maSin es deni iwvevs meore erTsaxela momWeris potencialis gazrdas, rac damtkicebulia eqsperimentiT [73].

erTfaza transformatoris pirveladi gragnili, romelic warmodgens energiis mimRebs mierTebuls energiis wyarosTan da mis erTsaxela momWerSi Semavali cvladi $i_1$ deni qmnis cvlad magnitur nakads $\Phi_1$–s, romelic $i_1$ denTan dakavSirebulia marjvena burRis wesiT. nax.3.1-ze mocemuli gragnilebis daxvevis SemTxvevaSi $\Phi_1$ nakads aqvs pirveladi gragnilis gularSi erTsaxela momWeris mxridan Semavali mimarTuleba da pirvelad gragnilSi aRZravs TviTinduqciis emZ-s.

$$e_{1L} = -\frac{d\Phi_1}{dt} = -L_1 \frac{di_1}{dt}, \qquad (\Phi_1 = L_1 i_1) \tag{3.1}$$




nax.3.1.erTfaza transformatoris principuli sqema

lencis wesis Tanxmad, niSani(-) miuTiTebs imaze, rom am emZ-s aqvs $i_1$ denis sawinaaRmdego mimarTuleba, rac naCvenebia nax.3.1-ze, xolo meoradi gragnilis gularSi, romelic warmoadgens energiis wyaros, am nakads erTsaxela momWeris mimarT aqvs gamomavali mimarTuleba da aRZravs masSi urTierTinduqciis emZ-s.

$$e_2 M = -\left(-\frac{d\Phi_{21}}{dt}\right) = M\frac{di_1}{dt}; (\Phi_{21} = Mi_1) \tag{3.2}$$

sadac frCxilebSi moTavsebuli niSani (-) aris lencis niSani, xolo frCxilebs gareTa niSani gviCvenebs, rom $\Phi_1$ nakadma

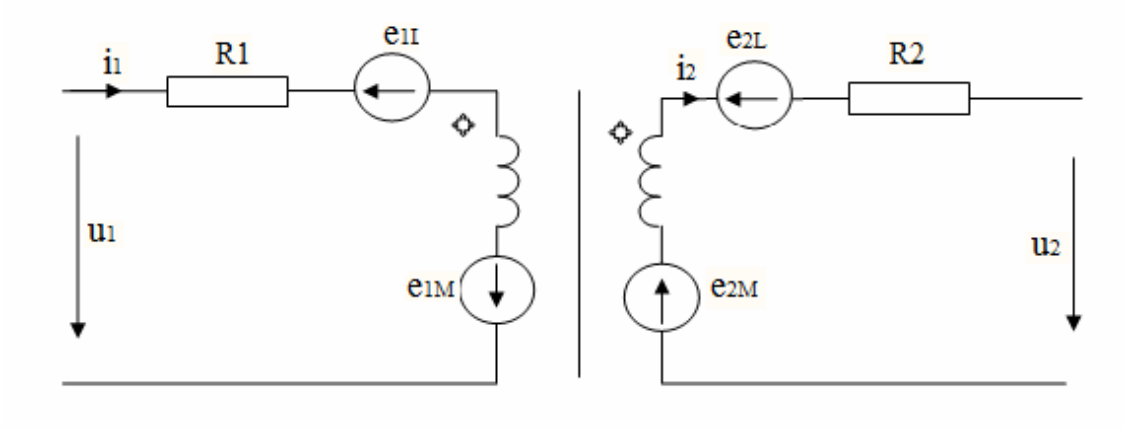
pirveladi gagnilis gularTan SedarebiT meore gagnilis gularSi Seicvala Sesvlis mimarTuleba erTsaxela momWeris mimarT. am nakadis cvlilebiT aRZruli $e_{2M}$ ki ar ewinaaRmdegeba $i_2$ dens, aramed radgan meore gagnili warmoadgens energiis wyaros, amitom am wyaros emZ aris swored $e_{2M}$ , romelic qmnis $i_2$ dens da aqvs am denis mimarTuleba. analogiurad $i_2$ deni qmnis $\Phi_2$ nakads da meorad gagnilSi aRZravs

$$e_{1L} = -\frac{d\Phi_2}{dt} = L_{12}\frac{di_2}{dt}; \quad (\Phi_2 = L_2 i_1) \tag{3.3}$$

TviTinduqciis emZ-s, romlis mimarTuleba nax. 3.1-ze iqneba denis sawinaaRmdego mimarTulebis xolo pirvelad gagnilSi aRiZvreba urTierTinduqciis emZ

$$e_{1M} = -\left(\frac{d\Phi_{12}}{dt}\right) = M\frac{di_2}{dt}; \quad (\Phi_{12} = M i_2) \tag{3.4}$$

romelsac eqneba $i_1$ denis Tanxvdenili mimarTuleba




nax.3.2 erTfaza transformatoris Canacvlebis sqema

nax. 3.1-ze mocemuli sqemis eqvivalenturi Canacvlebis sqemas aqvs nax. 3.2-ze mocemuli saxe

nax. 3.2-ze mocemuli Canacvlebis sqemisaTvis kirxhofis II kanonis safuZvelze vwerT gantolebaTa sistemas (Semovlis mimarTuleba emTxveva denebis mimarTulebas).

I konturi $e_{1M} - e_{1L} = i_1 R_1 - u_1$ (3.5)

II konturi $e_{2M} - e_{2L} = i_1 R_2 + u_2$ (3.6)

anu Zabvebis mixedviT

$$u_1 = i_1 R_1 + e_{1L} - e_{1M} = i_1 R_1 + L_1 \frac{di_1}{dt} - M \frac{di_2}{dt} \qquad (3.7)$$

$$u_2 = -i_2 R_2 - e_{2L} + e_{2M} = -i_2 R_2 - L_2 \frac{di_2}{dt} + M \frac{di_2}{dt} \qquad (3.8)$$

(3.7) da (3.8) kompleqsur saxeSi Semdegnairad Caiwereba

$$\dot{U}_1 = \dot{I}_1 (R_1 + j\omega L_1) - \dot{I}_2 j\omega M = \dot{I}_1 \underline{Z}_1 - \dot{I}_2 \underline{Z}_M \qquad (3.9)$$

$$\dot{U}_2 = \dot{I}_2 (R_2 + j\omega L_2) - \dot{I}_1 j\omega M = -\dot{I}_2 \underline{Z}_2 - \dot{I}_1 \underline{Z}_M \qquad (3.10)$$

(3.7) da (3.8) gantolebebi gviCvenebs, rom mcdaria sayovelTaod miRebuli formulireba imis Sesaxeb, rom TviTinduqciis koeficientebi erTfaza transformatorSi $L_1$ da $L_2$ yovelTvis dadebiTia, xolo urTierTin-duqciis koeficienti M SeiZleba iyos, rogorc dadebiTi ise uaryofiTi. aRniSnuli koeficientebi aris geometriuli sidideebi da yovelTvis dadebiTi ricxvebia, xolo dadebiTi da uaryofiTi niSnebi gantolebebis wevrebis win ganpirobebulia nakadebisa da denebis mimarTulebiT erTsaxela momWerebis mimarT. aRniSnuli sakiTxi damtkicebulia naSromSi [74]. aRniSnuli sakiTxis zusti gadawyvetis meti damajereblobisaTvis movitanT amerikeli fizikosis robert j. distintis naSroms [75], sadac mocemulia, rom faradeis kanoni $e = -N \frac{d\Phi}{dt}$ aris klasikuri mamoZravebeli eleqtruli kanonis mxolod gansakuTrebuli SemTxveva. Tu faradeis kanonSi $\frac{d\Phi}{dt}$ ganmartebulia, rogorc nakadis cvlilebis siCqare konturSi, maSin dadebiTi $\frac{d\Phi}{dt}$ miuTiTebs, rom nakadi Sedis konturSi. am dakvirvebis Sedegad faradeis kanoni Semdegnairad Caiwereba:

$$e = -N \frac{d\Phi}{dt} \text{ (Semsvleli)} = N \frac{d\Phi}{dt} \text{ (gamomsvleli)} \qquad (3.11)$$

aqedan gamomdinareobs, rom konturSi faradeis kanoni warmoqmnis uaryofiT emZ-s Semsvleli nakadisaTvis da dadebiT emZ-s gamomsvleli nakadisaTvis [75].

amrigad, imisaTvis, rom SevadginoT kirxhofis gantolebaTa sistema erTfaza transformatorisaTvis, induqcirebuli denebisa da emZ-ebis mimarTulebebi ki ar unda SevirCioT nebismierad, rogorc es dRemde literaturaSia, aramed unda ganvsazRvroT energiis Senaxvis kanonis Tanaxmad da davakanonoT erTxel da samudamod, rom urTierTinduqcia pirvelad da meorad gragnilebs Soris uaryofiTia, xolo meorad gragnilebs Soris dadebiTi. amasTanave unda gaviTvaliswinoT nakadebis mimarTuleba erTsaxela momWerebis mimarT. amiT cxadia, gamartivdeba analizisa da sinTezis amocanebis gadawyveta. ar iqneba Seusabamoba Teoriasa da praqtikas Soris. [76].

### 3.3 samfaza transformatoris maTematikuri modelis mniSvneloba da saWiroeba

samfaza transformatoris swori maTematikuri modelis Sedgenas da gamoyenebas udidesi mniSvneloba eniWeba transformatoris optimaluri parametrebis dasadgenad. dRemde ar arsebobs transformatorebis srulyofili maTematikuri modeli, miuxedavad imisa, rom evropis masStabiT transformatorebis parki Seadgens 4 milionze mets da transformatorebi xasiaTdebian sakmaod maRali margi qmedebis koeficientiT, daaxloebiT 99%. miuxedavad amisa danakargebi gvaqvs eleqtroenergiis moZraobis TiToeul ubanze, rac dakavSirebulia Zabvebis gardaqnasTan. Tanamedrove qselebSic ki transformatoruli gardamqmnelebiT danakargebi Seadgens mTlianad warmoebuli energiis 2%-s anu mTliani danakargebis 1/3-s.

sabazro urTierTobebis ganviTarebasTan erTad izrdeba energiis Rirebuleba, romelic mZime tvirTad awevs aramarto mosaxleobas aramed warmoeba aramed warmoeba-dawesebulebebs. amitom mTeli evropis masStabiT udidesi mniSvneloba eniWeba energoekonomiuri gamanawilebeli transformatorebis gamoyenebas. 2005 wlis monacemebiT evrokavSirSi energoekonomiuri transformatorebis gamoyenebiT daizoga weliwadSi daaxloebiT

22 mlrd kv/sT energia, ramac Seadgina 1.171 mlrd. evro fulad gamosaxulebebSi [77].

cnobilia rom transformatori xasiaTdeba uqmi svlisa da mokled SerTvis anu datvirTvis danakargebiT.

mokled SerTvis danakargebis Semcireba SeiZleba Semdegi RonisZiebebis gatarebiT:

-gragnilis gamtaris kveTis gazrdiT, rasac mivyavarT winaRobis Semcirebamde da Sesabamisad mcirdeba danakargebic, magram am SemTxvevaSi izrdeba transformatoris gabaritebi da Riribuleba.

-maRali gamtarobis masalebis gamoyeneba, TviT zegamtarobamde, magram am teqnologiebma jer-jerobiT ver miaRwies saWiro dones.

uqmi svlis danakargebi SeiZleba Semcirdes Semdegi gziT:

-gularis kveTis gazrdiT, rasac mivyavarT gabaritebisa da Riribulebis gazrdamde

-gularis firfitebis sisqis Semcireba, rac amcirebs grigalur denebs.

- gularSi amorfuli metalebis gamoyeneba. am sakiTxSi yvelaze meti rezervebi gagvaCnia. sxvanairad rom vTqvaT danakargebis Semcirebis teqnikuri rezervebi mTlianad amowuruli ar aris da efeqturobis done SeiZleba amaRldes ukve cnobili teqnologiebisa da principebis gamoyenebiT.

unda gvaxsovdes rom konstruqciebis Semdgomi srulyofisaTvis mxedvelobaSi unda miviRoT mravali urTierTdakavSirebuli faqtori dawyebuli gabarituli zomebidan damTavrebuli xmauriT aseve minimumamde unda iqnas dayvanili teqnologiuri riski. aqedan gamomdinare srulyofili maTematikuri modelis saWiroeba aucilebelia. Cvens mier Sedgenili modeli iTvaliswinebs, rogorc transformatoris geometruli parmetrebis: gragnilebis xviaTa ricxvi, gularas saSualo sigrZe da ganivkveTis farTobi, aseve masalis Tvisebebs: gularas magnitur SeRwevadobasa da magnitur gamtarobas. amitom transfor-

matorebis optimaluri parametrebis dasadgenad aRniSnuli maTematikuri modeli did daxmarebas gauwevs transformatorebis daproeqtebisa da kvlevis saqmeSi dasaqmebul specialistebs.

### 3.4 samfaza transformatoris maTematikuri modeli uqmi svlis reJimSi

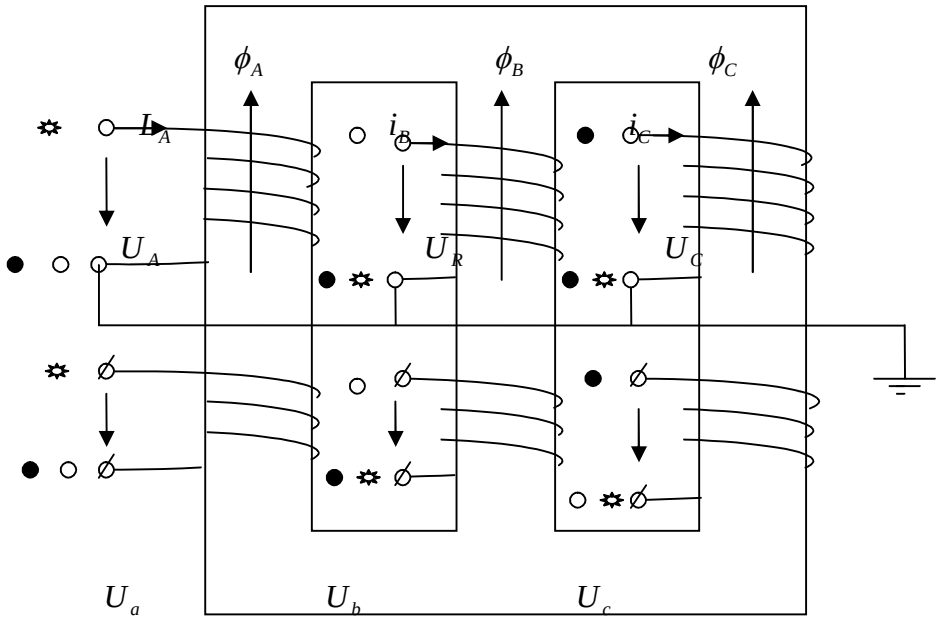
samfaza transformatorSi adgili aqvs sami saxis eleqtromagnitur induqcias: TviTinduqcia, urTierTinduqcia uaryofiTi magnituri kavSiriT da urTierTinduqcia dadebiTi magnituri kavSiriT. imisaTvis rom sworad SevadginoT kirxhofis wonasworobis diferencialuri gantolebebis sistema, pirvel rigSi saWiroa sworad movniSnoT erTsaxela momWerebi, ganvsazRvroT induqcirebuli denebisa da emZ-ebis mimarTuleba erTsaxela momWerebis mimarT, induqcirebuli emZ-ebi ganvixiloT rogorc gareSe emZ-ebi da amis Semdeg daviwyoT gantolebaTa sistemis Sedgena wrfivi eleqtruli wredebis Teoriis safuZvelze [78].

ganvixiloT uqmi svlis reJimi, anu roca meoreuli gragnilebi gaTiSulia $(i_a = i_b = i_c = 0)$. pirveladi gragnilebis boloebi gaerTianebulia erT wertilSi da damiwebulia. am SemTxvevaSi miiReba SeerTeba (⅄/⅄) da gragnilebis sawyisebis potencialebi miwis mimarT gansazRvraven Sesabamis fazur Zabvebs. pirvelad gragnilebze modebulia sinusoiduri Zabvebi:

$$\left.\begin{aligned} u_A &= U_m Sin\omega t \\ u_B &= U_m Sin(\omega t - 120^0) \\ u_C &= U_m Sin(\omega t + 120^0) \end{aligned}\right\} \qquad (3.12)$$

es modebuli Zabvebi ganapirobeben pirvelad gragnilebSi Sesabamisi $i_a, i_b$ da $i_c$ denebis gavlas. es denebi gragnilebSi qmnian $\Phi_A, \Phi_B, \Phi_C$ magnitur nakadebs, romlebic ikvrebian magnituri gamtaris anu foladis gularis gavliT. rogorc viciT, magnituri nakadis wirebi Sekruli wirebia da foladis gularSi gavlis dros es nakadebi erTmaneTis sawinaaRmdegod ikvrebian. TiToeul koWaSi gamavali denis mier Seqmnili nakadi gavlenas

axdens danarCeni ori fazis gularze da rogorc nax.3.3-dan Cans magnitur nakadebs aqvT Semxvedri mimarTuleba e.i. urTierTinduqciuroba uaryofiTia.




nax. 3.3. samfaza transformatoris eqvivalenturi Canacvlebis sqema

amitom aRniSnuli sqemis diferencialuri gantolebebis sistemas mocemul reJimSi eqneba saxe:

$$\left.\begin{aligned} u_A &= i_A R_A + L_A \frac{di_A}{dt} - M_{AB}\frac{di_B}{dt} - M_{AC}\frac{di_C}{dt} \\ u_B &= i_B R_B - M_{BA}\frac{di_A}{dt} + L_B \frac{di_B}{dt} - M_{BC}\frac{di_C}{dt} \\ u_C &= i_C R_C - M_{CA}\frac{di_A}{dt} - M_{CB}\frac{di_B}{dt} + L_C \frac{di_C}{dt} \end{aligned}\right\} \qquad (3.13)$$

Tu mocemul gantolebaTa sistemaSi maTi simciris gamo ugulvebelvyofT Zabvis vardnebs aqtiur winaRobebze: $i_A R_A, i_B R_B, i_C R_C$, maSin (3.13) gantolebaTa sistema kompleqsur saxeSi SegviZlia warmovadginoT Semdegi saxiT:

$$\left.\begin{aligned} \dot{U}_A &= j\omega L_A \dot{I}_A - j\omega M_{AB}\dot{I}_B - j\omega M_{AC}\dot{I}_C \\ \dot{U}_B &= -j\omega M_{BA}\dot{I}_A - j\omega L_B \dot{I}_B - j\omega M_{BC}\dot{I}_C \\ \dot{U}_C &= -j\omega M_{CA}\dot{I}_A - j\omega M_{CB}\dot{I}_B - j\omega L_C \dot{I}_C \end{aligned}\right\} \qquad (3.14)$$

aqedan gamomdinare induqciurobis matricas samfaza trasformatorisaTvis uqmi svlis reJimSi eqneba saxe:

$$\begin{vmatrix} L_A & -M_{AB} & -M_{AC} \\ -M_{BA} & L_B & -M_{BC} \\ -M_{CA} & -M_{CB} & L_c \end{vmatrix} \qquad (3.15)$$

(3.15) matricaSi $M_{AB} = M_{BA}$; $M_{BC} = M_{CB}$; $M_{AC} = M_{CA}$ e.i. uqmi svlis reJimSi gvaqvs urTierTinduqciurobis sami koeficienti, romelTagan yvela uaryofiTia.

(3.14) gantolebaTa sistemidan ganisazRvrebian uqmi svlis denebi pirvelad gragnilSi. am denebis mier Seqmnili $\Phi_A, \Phi_B, \Phi_C$ magnituri nakadebi ganWolaven ra meoradi gragnilis xviebs daainduqcireben maTSi urTierTinduqciis emZ-ebs, romlebic gansazRvraven Sesabamisi uqmi svlis Zabvebs meoradi gragnilis momWerebze, romlebTa warmodgena diferencialur saxeSi Semdegnairad xdeba (Zabvis vardnebi aqtiur winaRobaze ugulvebelyofilia):

$$\left.\begin{aligned} l_a &= -u_a = -M_{aA}\frac{di_A}{dt} + M_{aB}\frac{di_B}{dt} + M_{aC}\frac{di_C}{dt} \\ l_b &= -u_b = M_{bA}\frac{di_A}{dt} - M_{bB}\frac{di_B}{dt} + M_{bC}\frac{di_C}{dt} \\ l_c &= -u_c = M_{cA}\frac{di_A}{dt} + M_{cB}\frac{di_B}{dt} - M_{cC}\frac{di_C}{dt} \end{aligned}\right\} \qquad (3.16)$$

miRebuli gantolebaTa sistema kompleqsur saxeSi Semdegnairad Caiwereba:

$$\left.\begin{aligned} \dot{E}_a &= -\dot{U}_a = -j\omega M_{aA}\dot{I}_A + j\omega M_{aB}\dot{I}_B + j\omega M_{aC}\dot{I}_C \\ \dot{E}_b &= -\dot{U}_b = j\omega M_{bA}\dot{I}_A - j\omega M_{bB}\dot{I}_B + j\omega M_{bC}\dot{I}_C \\ \dot{E}_c &= -\dot{U}_c = j\omega M_{cA}\dot{I}_A + j\omega M_{cB}\dot{I}_B - j\omega M_{cC}\dot{I}_C \end{aligned}\right\} \qquad (3.17)$$

(3.17) gantolebaTa sistemidan ganisazRvreba transformatoris meorad gragnilebSi dainduqcirebuli emZ-ebi, romlebic uqmi svlis reJimSi am gragnilebis boloebze modebuli Zabvebis tolia Sebrunebuli niSniT.

## 3.5. samfaza transformatoris maTematikuri modeli datvirTvis reJimSi

maTematikuri modelireba warmoadgens adamianis mier gare samyaros movlenebis Secnobis erT-erT ZiriTad instruments. igi aris realuri obieqtis, procesis an sistemis Seswavlis saSualeba maTi maTematikuri modeliT Secvlis gziT, romelic ufro mosaxerxebelia gamomTvleli manqanis gamoyenebiT eqsperimentuli kvlevebis Catarebisas. maTematikuri modelirebis qveS igulisxmeba Sesaswavli movlenis ZiriTadi kanonzomierebani da kavSirebi. igi samecniero-teqnikuri progresis ganuyofeli nawilia. Ees aris meTodologia, romelic ar cvlis samecniero disciplinebs, ar uwevs maT konkurencias, magram monawileobs yvela sferoSi mimdinare SemoqmedebiT kvlevebSi.

maTematikuri modelis ageba niSnavs ama Tu im processa da movlenas Soris kavSiris gansazRvras, maTematikuri aparatis Seqmnas, romelic saSualebas gvaZlevs raodenobrivad da xarisxobrivad gamovsaxoT kavSiri specialistisaTvis saintereso fizikur sidideebsa da im faqtorebs Soris, romlebic gavlenas axdenen saboloo Sedegze.

maTematikuri modelirebis warmatebas ganapirobebs yvela Semadgeneli rgolis erTnairad Rrma damuSaveba. triadaze modeli-algoriTmi-programa dayrdnobiT mkvlevars xelT aqvs universaluri, moqnili da iafi instrumenti, romelic Tavidan yalibdeba sacdeli amocanebis nakrebis gadawyvetis safuZvelze.

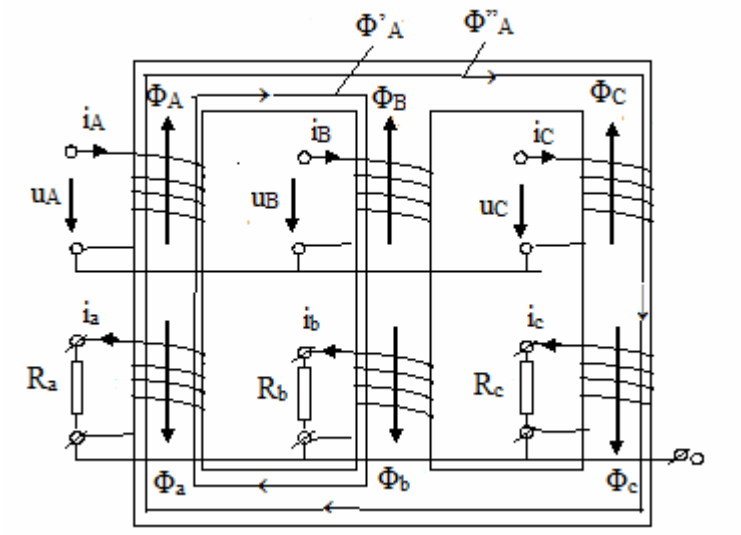
gasuli saukunis 60-70 wlebi gansakuTrebiT nayofieri gamodga eleqtroteqnikis Teoriuli problemebis ganviTarebis TvalsazrisiT. egm-is ganviTarebam, maTi gamoyenebis efeqturobis aucilebelma amaRlebam gansazRvra eleqtruli wredebis Teoriis sferoSi axali Teoriuli midgomebis damuSaveba. egm-is unarma daimaxsovros ricxvTa didi masivebi, Seasrulos logikuri operaciebi, aiZula mecnierebi gadaexedaT eleqtruli wredis gaangariSebis meTodebisaTvis. warmoiqmna im meTodebis ganviTarebis moTxovna, romlebic yvelaze metad gamoiyeneben egm-

is specifikur Tavisebur ebebs. aseT meTodebs miekuTvneba eleqtruli wredebis ganto lebebis formirebisa da amoxsnis matricu li meTodebi. Catarebu li didi mocu lobis samuSaos miuxedavad, eleqtroteqnikis Teoriu li prob lemebis ganviTarebis TvalsazrisiT ufro da ufro auci lebe li xdeba mimdinare procesis fizikuri mxaris gageba da amis safuZve l ze miRebu li Sedegebis WeSmaritebis Sefaseba.

zusti informaciis gadacemisa da gardaqmnis sakiTxTan dakavSirebiT, mizanSewoni lia eleqtruli wredebis Teoriis zogierTi sakiTxis gadmocemis meTodikaSi garkveu li cvli le-bebis Setana. magaliTad, aseT sakiTxs miekuTvneba induqciurad dakavSirebu li wredebis maTematikuri mode lebi, rom lis tipiuri magaliTia eleqtroenergiis gadacemis umniSvne lovanesi e lementi – samfaza transformatori.

nax.3.4-ze naCvenebia datvirTu li samfaza transformatoris magnituri nakadebis mimarTu lebani, rome lic Sesabamis denTad dakavSirebu lia burRis wesiT.

samuSaos mizania datvirTu li samfaza transformatoris ca lsaxa maTematikuri mode lis Sedgena, rome lic Seesabameba am transformatorSi mimdinare fizikur procesebs.




nax.3.4 datvirTu li samfaza transformatoris magnituri nakadis mimarTu lebani.

rogorc cnobilia magnituri nakadebis wirebi Sekruli wirebia. TiToeuli fazis gragnilSi gamavali denis mier Seqmnili nakadi iyofa or nawilad da ganWolavs danarCeni ori fazis gragnilebis xviebs da aRZravs maTSi urTierTinduqciis emZ-ebs. magaliTad, A fazaSi gamavali $i_A$ denis mier Seqmnili nakadi $\Phi_A$ Sedgeba ori nawilisagan da tolia:

$$\Phi_A = \Phi'_A + \Phi''_A, \qquad (3.18)$$

am nakadis nawili $\Phi'_A$ ganWolavs B fazis rogorc maRali, ise dabali Zabvis gragnilebs da orive maTganSi aRZravs urTierTinduqciis emZ-ebs, xolo $\Phi''_A$ ganWolavs C fazis rogorc maRali ise dabali Zabvis gragnilebs da aseve maTSic aRZravs urTierTinduqciis emZ-ebs. analogiurad gveqneba danarCen fazebSi gamavali $i_B$ da $i_C$ denebis mier Seqmnili $\Phi_B$ da $\Phi_C$ magnituri nakadebisaTvisac, romlebic Sesabamisad ganWolaven A,C da A,B fazebis maRali da Ddabali Zabvis gragnilebs (naxazis gadatvirTvis gamo $\Phi'_B, \Phi''_B, \Phi'_C$ da $\Phi''_C$ nakadebi naCvenebi ar aris).

transformatorebis gantolebebis Sedgenisas naSromSi [78] calsaxad gaTvaliswinebulia mxolod erTsaxela momWerebi da transformatoris pirvelad da meoreul gragnilebs Soris urTierTinduqciurobis uaryofiTi niSani, magram gaTvaliswinebuli ar aris Tu romel sistemaSia Cawerili gantolebaTa sistema. aseve igi Sedgenilia im SemTxvevisaTvis, rodesac transformatoris meoreuli gragnili mokled aris SerTuli. naSromSi [79] damtkicebulia, rom Semxvedri SeerTebis mqone induqciurad dakavSirebul wredebisaTvis gantolebaTa sistemis SedgenisaTvis gaTvaliswinebuli unda iqnes erTsaxela momWerebi, urTierTinduqciis uaryofiTi niSani da sistemis yvela gantoleba unda Caiweros raime erTsa da imave aTvlis sistemaSi.

aRniSnulidan gamomdinare nax.3.4-ze mocemuli sqemisaTvis vadgenT gantolebaTa sistemas kirxhofis II kanonis safuZvelze $\Phi_A$ nakadis aTvlis sistemaSi. Tu gaviTvaliswinebT, rom meoreul gragnilSi:

$$u_a = i_a R_a \quad ; \; u_b \quad = i_b R_b ; \quad u_c = i_c R_c \tag{3.19}$$

maSin gveqneba:

$$\begin{aligned}
u_A &= r_A i_A + L_A \frac{di_A}{dt} - M_{Aa}\frac{di_a}{dt} - M_{AB}\frac{di_B}{dt} + M_{Ab}\frac{di_b}{dt} - M_{AC}\frac{di_C}{dt} + M_{Ac}\frac{di_c}{dt} \\
-u_a &= r_a i_a - M_{aA}\frac{di_A}{dt} + L_a \frac{di_a}{dt} + M_{aB}\frac{di_B}{dt} - M_{ab}\frac{di_b}{dt} + M_{aC}\frac{di_C}{dt} - M_{ac}\frac{di_c}{dt} \\
u_B &= r_B i_B - M_{BA}\frac{di_A}{dt} + M_{Ba}\frac{di_a}{dt} - L_B \frac{di_B}{dt} - M_{Bb}\frac{di_b}{dt} - M_{BC}\frac{di_C}{dt} + M_{Bc}\frac{di_c}{dt} \\
-u_b &= r_b i_b + M_{bA}\frac{di_A}{dt} - M_{ba}\frac{di_a}{dt} - M_{bB}\frac{di_B}{dt} + L_b \frac{di_b}{dt} + M_{bC}\frac{di_C}{dt} - M_{bc}\frac{di_c}{dt} \\
u_C &= r_C i_C - M_{CA}\frac{di_A}{dt} + M_{Ca}\frac{di_a}{dt} - M_{CB}\frac{di_B}{dt} + M_{Cb}\frac{di_b}{dt} + L_c \frac{di_C}{dt} - M_{Cc}\frac{di_c}{dt} \\
-u_c &= r_c i_c + M_{cA}\frac{di_A}{dt} - M_{ca}\frac{di_a}{dt} + M_{cB}\frac{di_B}{dt} - M_{cb}\frac{di_b}{dt} - M_{cC}\frac{di_C}{dt} + L_c \frac{di_c}{dt}
\end{aligned} \tag{3.20}$$

(3.19) is gaTvaliswinebiT da gantolebaTa sistemis wevrobriv dalagebiT (3.20) sistema kompleqsur saxeSi miiRebs (3.21) saxes:

$$\begin{aligned}
\dot{U}_A &= (r_A + j\omega L_A)\dot{I}_A - j\omega M_{Aa}\dot{I}_a - j\omega M_{AB}\dot{I}_B + j\omega M_{Ab}\dot{I}_b - j\omega M_{AC}\dot{I}_C + j\omega M_{Ac}\dot{I}_c \\
0 &= -j\omega M_{aA}\dot{I}_A + (r_a + R_a + j\omega L_a)\dot{I}_a + j\omega M_{aB}\dot{I}_B - j\omega M_{ab}\dot{I}_b + j\omega M_{aC}\dot{I}_C - j\omega M_{ac}\dot{I}_c \\
\dot{U}_B &= -j\omega M_{BA}\dot{I}_A + j\omega M_{Ba}\dot{I}_a + (r_B + j\omega L_B)\dot{I}_B - j\omega M_{Bb}\dot{I}_b - j\omega M_{BC}\dot{I}_C - j\omega M_{Bc}\dot{I}_c \\
0 &= j\omega M_{bA}\dot{I}_A - j\omega M_{ba}\dot{I}_a - j\omega M_{bB}\dot{I}_B + j\omega (r_b + R_b + j\omega L_b)\dot{I}_b + j\omega M_{bC}\dot{I}_C - j\omega M_{bc}\dot{I}_c \\
\dot{U}_C &= -j\omega M_{CA}\dot{I}_A + j\omega M_{Ca}\dot{I}_a - j\omega M_{CB}\dot{I}_B + j\omega M_{Cb}\dot{I}_b + (r_C + j\omega L_C)\dot{I}_C - j\omega M_{Cc}\dot{I}_c \\
0 &= j\omega M_{cA}\dot{I}_A - j\omega M_{ca}\dot{I}_a + j\omega M_{cB}\dot{I}_B - j\omega M_{cb}\dot{I}_b - j\omega M_{cC}\dot{I}_C + (r_c + R_c + j\omega L_c)\dot{I}_c
\end{aligned} \tag{3.21}$$

miRebul gantolebaTa sistemaSi, datvirTvis winaRobasTan SedarebiT, maTi Zalian mcire mniSvnelobebis gamo SeiZleba ugulvebelvyoT gragnilebis aqtiuri winaRobebi $r_A, r_B, r_C, r_a, r_b, r_c$, ris Semdegac SeiZleba SevadginoTY winaRobaTa matrica, romelsac aqvs qvemoT moyvanili saxe:

$$\begin{Vmatrix}
j\omega L_A & -j\omega M_{Aa} & -j\omega M_{AB} & j\omega M_{Ab} & -j\omega M_{AC} & j\omega M_{Ac} \\
-j\omega M_{aA} & (R_a + j\omega L_A) & j\omega M_{aB} & -j\omega M_{ab} & j\omega M_{aC} & -j\omega M_{aC} \\
-j\omega M_{BA} & j\omega M_{Ba} & j\omega L_B & -j\omega M_{Bb} & -j\omega M_{BC} & j\omega M_{Bc} \\
j\omega M_{bA} & -j\omega M_{ba} & -j\omega M_{bB} & (R_b + j\omega L_b) & j\omega M_{bC} & -j\omega M_{bc} \\
-j\omega M_{CA} & j\omega M_{ca} & -j\omega M_{CB} & j\omega M_{Cb} & j\omega L_c & -j\omega M_{Cc} \\
j\omega M_{cA} & -j\omega M_{ca} & j\omega M_{cB} & -j\omega M_{cb} & -j\omega M_{cC} & (R_c + j\omega L_c)
\end{Vmatrix} \tag{3.22}$$

mocemul (3.22) winaRobaTa matricaSi zogierTi koeficienti erTmaneTis tolia. davadginoT toli koeficientebi da SemovitanoT gamartivebuli aRniSvnebi [80]. transformatoris pirveladi gragnilebis xviaTa ricxvebi erTmaneTis tolia $W_A = W_B = W_C = W_1$. Ш-s magvari gularis A da C fazebis magnituri gamtarebis saSualo sigrZe erTmaneTis tolia $\square_A = \square_C$, xolo $\square_B$ gansxvavebulia, amitom fazebis pirveladi gragnilebis induqciurobebi tolia:

$$L_A = L_C = W_1^2 \lambda_1 = W_1^2 \mu\mu_0 \frac{l_1}{S}$$
$$L_B = W_1^2 \lambda_2 = W_1^2 \mu\mu_0 \frac{l_2}{S} \qquad (3.23)$$

sadac, $\mu$ – magnitogamtaris fardobiTi magnituri SeRwevadobaa da misi mniSvneloba aiReba specialuri cxrilebidan foladis markis mixedviT; $\mu_0$ - vakuumis magnituri SeRwevadoba da tolia $\mu_0 = 4\pi 10^{-7}$ hn/m; S – magnituri gamtaris ganivkveTis farTobia.

analogiurad meoreuli gragnilebisaTvis gveqneba:

$$L_a = L_c = W_2^2 \lambda_1 = W_2^2 \mu\mu_0 \frac{l_1}{S}$$
$$L_b = W_2^2 \lambda_2 = W_2^2 \mu\mu_0 \frac{l_2}{S} \qquad (3.24)$$

SeiZleba miviRoT, rom gragnilebs Soris kavSiris koeficienti K=1 amitom urTierTinduqciurobebi tolia:

$$M_{AB} = M_{BA} = M_{BC} = M_{CB} = K\sqrt{L_A L_B} = M_1;\ M_{AC} = M_{CA} = K\sqrt{L_A L_C} = M_2$$
$$M_{ab} = M_{ba} = M_{bc} = M_{cb} = K\sqrt{L_a L_{Bb}} = M_3;\ M_{ca} = M_{ac} = K\sqrt{L_c L_a} = M_4$$
$$M_{Aa} = M_{aA} = M_{Cc} = M_{cC} = M_{Ac} = M_{cA} = M_{Ca} = M_{aC} = K\sqrt{L_A L_a} = M_5 \qquad (3.25)$$
$$M_{Ab} = M_{bA} = M_{Cb} = M_{bC} = K\sqrt{L_A L_b} = M_6;\ M_{Bb} = M_{bB} = K\sqrt{L_B L_b} = M_7$$
$$M_{Ba} = M_{aB} = M_{Bc} = M_{cB} = K\sqrt{L_B L_a} = M_8$$

gragnilebis sruli winaRobebi tolia:

$$\underline{Z}_A = j\omega L_A = Z_A e^{j90^\circ}, \text{ sadac } Z_A = \omega L_A;$$

$$\underline{Z}_a = R_a + j\omega L_a = \sqrt{R_a^2 + (\omega L_a)^2}\, e^{j\operatorname{arctg}\frac{\omega L_a}{R_a}} = Z_a e^{j\varphi_a}$$

$$Z_a = \sqrt{R_a^2 + (\omega h_a)^2}\ ;\ \varphi_a = arctg\frac{\omega L_a}{R_a}$$

$$\underline{Z}_B = j\omega L_B = Z_B e^{j90^\circ};\ \text{sadac}\quad Z_B = \omega L_B$$

$$\underline{Z}_b = R_b + j\omega L_b = \sqrt{R_b^2 + (\omega L_b)^2}\, e^{j\operatorname{arctg}\frac{\omega L_b}{R_b}} = Z_b e^{j\varphi_b} \qquad (3.26)$$

$$Z_b = \sqrt{R_b^2 + (\omega L_b)^2}\ ;\quad \varphi_b = arctg\frac{\omega L_b}{R_b}$$

$$\underline{Z}_C = j\omega L_C = Z_C e^{j90^\circ};\ \text{sadac}\ Z_C = \omega L_C$$

$$\underline{Z}_c = R_c + j\omega L_c = \sqrt{R_c^2 + (\omega L_c)^2}\, e^{j\operatorname{arctg}\frac{\omega L_c}{R_c}} = Z_c e^{j\varphi_c}$$

$$Z_c = \sqrt{R_c^2 + (\omega L_c)^2}\ ;\quad \varphi_c = arctg\frac{\omega L_c}{R_c}$$

radgan samrewvelo sixSire $f = 50$ hc, amitom yvela SemTxvevaSi $\omega = 2\pi f = 314$ radiani/wm; xolo (3.23), (3.24), (3.25) da (3.26)-is gaTvaliswinebiT (3.22) winaRobebis matrica miiRebs saxes:

$$\begin{Vmatrix} Z_A & -j\omega M_5 & -j\omega M_1 & j\omega M_6 & -j\omega M_2 & j\omega M_5 \\ -j\omega M_5 & Z_a & j\omega M_8 & -j\omega M_3 & j\omega M_5 & -j\omega M_4 \\ -j\omega M_1 & j\omega M_6 & Z_B & -j\omega M_7 & -j\omega M_1 & j\omega M_8 \\ j\omega M_6 & -j\omega M_3 & -j\omega M_7 & Z_b & j\omega M_6 & -j\omega M_3 \\ -j\omega M_2 & j\omega M_5 & -j\omega M_1 & j\omega M_6 & Z_C & -j\omega M_5 \\ j\omega M_5 & -j\omega M_4 & j\omega M_8 & -j\omega M_3 & -j\omega M_5 & Z_c \end{Vmatrix} \qquad (3.27)$$

(3.27) winaRobaTa matrica warmoadgens (3.21) sistemis mTavar ganmsazRvrels, anu

$$\Delta = \begin{Vmatrix} \dot{I}_A & \dot{I}_a & \dot{I}_B & \dot{I}_b & \dot{I}_C & \dot{I}_c \\ Z_A & -j\omega M_5 & -j\omega M_1 & j\omega M_6 & -j\omega M_2 & j\omega M_5 \\ -j\omega M_5 & Z_a & j\omega M_8 & -j\omega M_3 & j\omega M_5 & -j\omega M_4 \\ -j\omega M_1 & j\omega M_6 & Z_B & -j\omega M_7 & -j\omega M_1 & j\omega M_8 \\ j\omega M_6 & -j\omega M_3 & -j\omega M_7 & Z_b & j\omega M_6 & -j\omega M_3 \\ -j\omega M_2 & j\omega M_5 & -j\omega M_1 & j\omega M_6 & Z_C & -j\omega M_5 \\ j\omega M_5 & -j\omega M_4 & j\omega M_8 & -j\omega M_3 & j\omega M_6 & Z_c \end{Vmatrix} \qquad (3.28)$$

(3.28) sistemaSi TiToeuli saZiebeli denis qveS moTavsebulia maTi koeficientebi. garda mTavari determinantisa ($\Delta$) denebis gansazRvrisaTvis gvesaWiroeba damatebiTi ganmsazRvrelebi. damatebiTi ganmsazRvrelis misaRebad denebis qveS moTavsebuli koeficientebi unda Seicvalos (3.21) sistemis

marcxena nawilSi arsebuli Tavisufali wevrebiT. magaliTad $\dot{I}_A$ denis damatebiTi ganmsazRvreli ganisazRvreba (3.29) matriciT.

$$\Delta\dot{I}_A = \begin{Vmatrix} \dot{U}_A & -j\omega M_3 & -j\omega M_1 & j\omega M_6 & -j\omega M_2 & j\omega M_5 \\ 0 & Z_a & j\omega M_8 & -j\omega M_3 & j\omega M_5 & -j\omega M_4 \\ \dot{U}_B & j\omega M_6 & Z_B & -j\omega M_7 & -j\omega M_1 & j\omega M_8 \\ 0 & -j\omega M_3 & -j\omega M_7 & Z_b & j\omega M_6 & -j\omega M_3 \\ \dot{U}_C & j\omega M_5 & -j\omega M_1 & j\omega M_6 & Z_C & -j\omega M_5 \\ 0 & -j\omega M_4 & j\omega M_8 & -j\omega M_3 & j\omega M_6 & Z_c \end{Vmatrix} \quad (3.29)$$

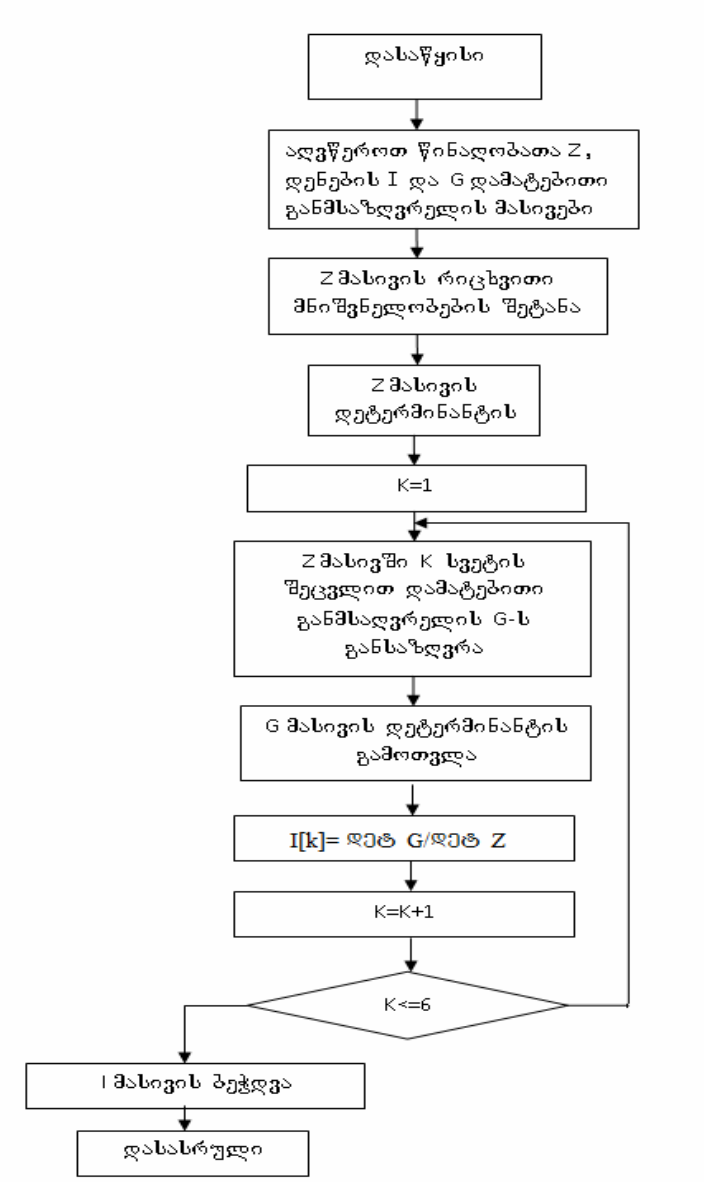
saZiebeli $\dot{I}_A$ deni ganisazRvreba formuliT:

$$\dot{I}_A = \Delta\dot{I}_A/\Delta \quad (3.30)$$

analogiurad ganisazRvreba danarCeni denebic:

$$\dot{I}_a = \Delta\dot{I}_a/\Delta\,;\quad \dot{I}_B = \Delta\dot{I}_B/\Delta;\ \dot{I}_b = \Delta\dot{I}_b/\Delta;\ \dot{I}_C = \Delta\dot{I}_c/\Delta;\ \dot{I}_c = \Delta\dot{I}_c/\Delta \quad (3.31)$$

denebis gansazRvrisaTvis nax.3.5-ze warmodgenilia transformatoris gantolebaTa sistemis amoxsnis blok-sqema, romlis mixedviTac SesaZlebelia programis Sedgena.




nax.3.5. datvirTuli samfaza transformatoris gantolebaTa sistemis amoxsnis blok-sqema.

# Tavi IV. Zaluri zeTiani transformatorebis diagnostikis Tanamedrove meTodebi

## 4.1. Zalur transformatorSi ganviTarebadi defeqtebis gansazRvris algoriTmi

Zaluri transformatoris daZvelebis procesSi misi izolacia ganicdis mTel rig fiziko - qimiur cvlilebebs. am dros gamoiyofa daSlis produqtebi – myari, Txevadi da airisebri nivTierebebi. celulozisagan damzadebuli myari saizolacio masalebi (qaRaldi da muyao) neli daZvelebis dros gamoyofen airebs; maT ricxvSia wyalbadi da dabalmolekuluri naxSirwyalbadebi, aseve naxSirbadis Jangi da orJangi, romlebic warmoiqmnebian celulozis daJangvisas. airebi warmoiSveba aseve zeTis daZvelebisas. amasTanave airis gamoyofis intensivoba damokidebulia eleqtruli velis daZabulobasa da zeTis qimiur Semadgenlobaze; obieqtis muSaobis reJimze; eqspluataciis xangrZlivobaze; gamoyenebul masalebze da mTel rig faqtorebze, romelTa gaTvaliswinebac yovelTvis advili ar aris gamoyofili airebis ricxvSi garda naxSiris Jangisa CO da orJangisa $CO_2$, gvaqvs aseve wyalbadi $HO_2$, meTani $CH_4$, eTani $C_2H_6$, eTileni $C_2H_4$ da acetileni $C_2H_2$ [54].

airebis zeTSi xsnadoba proporciulia gareSe wnevisa da 20-100$^0$C temperaturis diapazonSi temperaturis wrfivi funqciaa. magaliTad, wyalbadisaTvis zeTSi xsnadoba moculobaSi 7 %-ia, azotisa -8,6%, haerisa- 10,3 %, meTania -30 %,acetilinisa – 400 % da a.S.

izolaciis darRvevis dros, romelic dakavSirebulia dazianebis arsebobasTan airebis gamoyofis intensivobis procesi mkveTrad izrdeba; aseve SeiZleba Seicvalos airebis Semadgen-loba da maTi Tanafardoba.

dadgenilia, rom transformatoris defeqtis TiToeul saxes Seesabameba airebis gansazRvruli nakrebi da maTi Tanafardoba [55].

ganviTarebadi defeqtebis Sexaseb codnis baza Seicavs mraval wess, romelTagan TiToeuli xasiaTdeba ndobis koeficientiT. codnis bazis safuZvels Seadgens rekomendaciebi [56].

wesebis ndobis koeficienti damokidebulia masSi Semavali parametrebis gansazRvrulobaze. Tu erTi an ramdenime parametri gansazRvruli ar aris, maSin wesebis ndobis koeficienti mcirdeba, rac aisaxeba am wesebis gavleniT saboloo Sedegze. magaliTad, informaciis mTliani mocauloba sistemaSi miewodeba maSin, roca cnobilia yvela airis koncentraciebi. amasTanave nebismieri airis ricxviTi mniSvnelobebis gverdiT SesaZlebelia arsebobdes Semdegi SemTxvevebi:

- airi saerTod ar arsebobs;
- aris airis mcire raodenoba (kvali);
- airis arseboba an ar arseboba gansazRvruli ar aris.

ukanaskneli SemTxveva aris im wesis ndobis koeficientis cvlilebis mizezi, romelSic Sedis Sesabamisi airi. damuSavebuli algoriTmi iZleva saSualebas miviRoT diagnozi im SemTxvevaSic ki, roca erTi airi mainc namdvilad aris dafiqsirebuli, xolo danarCenebis mimarT ar gvaqvs mkafio informacia. bunebrivia, rom am SemTxvevebSi faqtiuri da prognozirebadi defeqtebis Tanxvedris albaToba mcirdeba.

transformatoris diagnostikis procesSi ramdenime gazomvis arsebobisas mimdevrobiT CairTveba axali wesebi da xdeba defeqtebis TandaTanobiTi dazusteba. miRebulia, rom transformators erTi airis koncentraciis zRvruli dasaSvebi mniSvnelobis gadametebis drosac ki gaaCnia defeqti.

TiToeuli transformatori defeqtis SemCnevis dros dgeba kontrolis qveS. situaciis dazustebis mizniT xuTi dRis Semdeg tardeba ganmeorebiTi analizi. morigi analizis dadebiTi Sedegis (ar aris defeqti) SemTxvevaSi dafiqsirdeba transformatorSi mimdinare procesebis normalizacia da transformatori avtomaturad moixsneba kontrolidan.

defeqtis prognozirebasTan erTad formirdeba transformatoris teqnikuri momsaxureobis Semdgomi RonisZiebebi. amdros dawvrilebiTYanalizdeba defeqtis ganviTarebis teqnologia, romelic xasiaTdeba niSnebiT 0 an 1.

magaliTisaTvis, ganvixiloT defeqtis ganviTarebis teqnologia transformatorSi airebis zRvruli koncentraciis analizis SemTxvevisaTvis.

- transformatorSi analizis momentSi defeqtebis arsebobis aRmricxveli avRniSnoT P1-iT. (Tu transformatorSi adgili aqvs zeTis zRvruli koncentraciis gadametebas, maSin igi tolia 0, xolo Tu ara –1);
- erTi airis mainc koncentraciis zrdis siCqare TveSi 10 %-ze metia - P2 ( 0 - zrda naklebia 10 %-ze, 1- zrda metia 10 %-ze);
- mocemul transformatorSi zedized defeqtebis SemCnevis raodenoba - P3 (0- SemCneuli defeqtebis raodenoba naklebia an toli 2-ze, 1- metia 2-ze);
- erTi airis mainc koncentraciis TveSi zrdis siCqaris 10%-ze meti zrdis zedized SemTxvevebis raodenoba - P4 (0- koncentraciis zrdis siCqare SemCneulia naklebi an toli 2-ze, 1- meti 2-ze);
- airebis zrdis daCqareba - P5 (0 - progresirebadi zrdis raodenoba yoveli Semdgomi gazomvisas naklebia an toli 1-ze, 1- metia 1-ze);
- faqtorebis arseboba, romlebic xels uwyoben airebis koncentraciis gardas -PP6 (0- faqtorebs aqvs adgili, 1- faqtorebi ar aris);
- faqtorebis arseboba, romlebic xels uwyoben airebis koncentraciis Semcirebas -PP7 (0- faqtorebs aqvs adgili, 1- faqtorebi ar aris);
- zeTis ukanasknel sinjSi acetilenis ZiriTadi airis saxiT arseboba - P8 (0- ar aris ZiriTadi airi, 1- aris ZiriTadi airi);

o zeTis ukanasknel sinjSi naxSirbadis Jangisa da orJangis ZiriTadi airis saxiT arseboba -P9 (0- sinjSi es airebi ar aris, 1- sinjSi aris erTi airi mainc);

**magaliTi.** CavataroT ТРДН-40000/110 Zalovani transformatoris diagnostikuri analizi cxrili 4.1-Si moyvanili zeTis erTeulovan moculobaSi airebis koncentraciis mniSvnelobebi wina da ukanasknели gazomvebis Sedegebis mixedviT.

analizi Catarebulia meorejer, defeqtis pirveli SemCnevidan erTi Tvis Semdeg.

cxrili 4.1. zeTis erTeulovan moculobaSi airebis koncentraciis mniSvnelobebi

| TariRi | $H_2$ | $CH_4$ | $C_2H_2$ | $C_2H_4$ | $C_2H_6$ | CO | $CO_2$ |
|---|---|---|---|---|---|---|---|
| 01.03.2011 | 0.002 | 0.01 | 0.001 | 0.02 | 0.7 | ganusazR. | 0.4 |
| 01.04.2011 | 0.003 | 0.02 | 0.02 | 0.05 | ganusazR. | ganusazR. | 0.5 |

pirvel rigSi unda ganvsazRvroT airebis zRurbluri, zRvruli, fardobiTi koncentraciisa da koncentraciis cvlilebis absoluturi da fardobiTi siCqareebi. yvela es parametri gansazRvrulia normebiTa da formulebiT. literatura [54] –is mixedviT maTi mniSvnelobebi moyvanilia cxrili 4.2 -Si.

cxrili 4.2. normebiT gansazRvruli parametrebi

| parametri | $H_2$ | $CH_4$ | $C_2H_2$ | $C_2H_4$ | $C_2H_6$ | CO | $CO_2$ |
|---|---|---|---|---|---|---|---|
| zRurbluri koncentrac. | 0.0005 | 0.0005 | 0.00005 | 0.0005 | 0.0005 | 0.005 | 0.005 |
| zRvruli koncentrac | 0.01 | 0.01 | 0.001 | 0.01 | 0.005 | 0.02 | 0.3 |
| fardobiTi koncentracia | 0.3 | 2 | 19.9 | 5 | ganusaz. | ganusaz. | 1.67 |
| koncentraciis cvlilebis absoluturi siCqare | 0,010 | 0.1071 | 0.2036 | 0.321 | ganusaz. | ganusaz. | 0.107 |
| koncentraciis cvlilebis fardobiTi siCqare | 53.571 | 107.143 | 2035.7 | 160.71 | ganusaz. | ganusaz. | 26.78 |

cxrili 4.2-is monacemebis safuZvelze fardobiTi koncentraciis mniSvnelobebis mixedviT xdeba airis koncentraciis xasiaTis gansazRvra. rogorc am cxrilis fardobiTi koncentraciis striqonidan Cans: $H_2$ - aris maxasiaTebeli airi mcire Semcvelobi T; $CH_4$ da $C_2H_4$ –arian maxasiaTebeli airebi maRali Semcvelobi T; $C_2H_2$ da $CO_2$ – ZiriTadi airebia; $C_2H_6$ da CO airebi ar arseboben.

rogorc cxrili 4.2 -dan Cans oTxi airis ($CH_4$, $C_2H_2$, $C_2H_4$, $CO_2$) fardobiTi koncentraciis mniSvnelobebi aRemateba zRvrul mniSvnelobebs. am dros mimdinareobs yvela airis koncentraciis zrda 10 %-ze meti absoluturi siCqariT. MmaSasadame, saxezea ganviTarebadi defeqtis arseboba. ganviTarebadi defeqtis arsebobis Semdeg SemuSavebuli unda iqnes rekomendaciaTa krebuli. erTi mxriv defeqtis damaxasiaTebel niSnebsa da misi ganviTarebis process, xolo meores mxriv defeqtis gamovlenis dazustebisa da Sedegebis lokalizaciis rekomendaciebis nakrebs Soris arsebobs garkveuli kavSiri, romelic moyvanilia cxrili 4.3 -Si

cxrili 4.3. kavSiri niSanTa da rekomendaciebis nakrebebs Soris.

| niSanTa nakrebi | | | | | | | | | rekomendaciebis nakrebi | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **P1** | **P2** | **P3** | **P4** | **P5** | **P6** | **P7** | **P8** | **P9** | **C1** | **C2** | **C3** | **C4** | **C5** | **C6** |
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 18 | 0 | 0 | 0 | 0 |
| 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 11 | 14 | 0 | 0 | 0 |
| 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 3 | 9 | 14 | 0 | 0 | 0 |
| 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 2 | 3 | 0 | 0 | 0 | 0 |
| 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| 1 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 3 | 10 | 15 | 18 | 0 | 0 |
| 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 6 | 7 | 9 | 14 | 0 |
| 1 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 3 | 4 | 9 | 0 | 0 | 0 |
| 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 3 | 9 | 15 | 0 | 0 | 0 |
| 1 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 2 | 3 | 15 | 0 | 0 | 0 |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 2 | 3 | 0 | 0 | 0 | 0 |
| 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 2 | 3 | 19 | 0 | 0 | 0 |
| 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 2 | 3 | 0 | 0 | 0 | 0 |
| 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 10 | 9 | 0 | 0 | 0 |
| 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 2 | 3 | 10 | 0 | 0 | 0 |
| 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 3 | 18 | 0 | 0 | 0 | 0 |
| 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 3 | 9 | 14 | 0 | 0 | 0 |
| 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 2 | 15 | 0 | 0 | 0 | 0 |
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 3 | 14 | 0 | 0 | 0 | 0 |
| 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 15 | 0 | 0 | 0 | 0 |
| 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 3 | 9 | 0 | 0 | 0 | 0 |
| 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 3 | 10 | 0 | 0 | 0 | 0 |
| 1 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 2 | 15 | 0 | 0 | 0 | 0 |
| 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 3 | 9 | 14 | 0 | 0 | 0 |
| 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 3 | 14 | 0 | 0 | 0 | 0 |
| 1 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 3 | 14 | 0 | 0 | 0 | 0 |
| ***1*** | ***1*** | ***0*** | ***0*** | ***0*** | ***1*** | ***1*** | ***1*** | ***1*** | ***2*** | ***3*** | ***0*** | ***0*** | ***0*** | ***0*** |
| 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 2 | 15 | 0 | 0 | 0 | 0 |

defeqtis ganviTarebis TiToeuli situacia erTmniSvnelovnad gansazRvravs niSnebis sias. Cvens mier moyvanil magaliTSi:

- adgili aqvs zRvruli koncentraciis gadaWarbebas, maSasadame P1=1.
- airebis koncentraciis zrdis siCqare metia 10 %-ze, maSasadame P2=1.
- SemCneuli defeqtebis raodenoba tolia 2, maSasadame P3=0.
- siCqaris 10 %-ze metad gadaWarbebis raodenoba tolia 1, maSasadame P4=0.
- nimuSSi pirvelad iqna dafiqsirebuli airebis zrdis maqsimaluri siCqare, maSasadame P5= 0.
- ar Catarebula iseTi RonisZiebani, romlebic xels uwyobdnen airebis koncentraciis zrdas, maSasadame P6 =1.
- ar Catarebula iseTi RonisZiebani, romlebic xels uwyobdnen airebis koncentraciis Secirebas, maSasadame P7 =1.

- acetileni nimuSSi ZiriTadi airia, maSasadame P8 =1.
- NnimuSSi adgili aqvs CO an CO2, maSasadame P9 =1.

miRebuli niSnebis sias cxrili 4.3 - Si Seesabameba qvemodan meore striqoni, romlis gaswvriv mocemulia saWiro RonisZiebebis nomrebi #2 da #3. am nomrebis mixedviT zeTSi gaxsnili airebis Sedegebis safuZvelze konkretuli gamocdebis prioritetul Catarebaze rekomendaciebi mocemulia cxrili 4.4-Si. am cxrilidan airCeva Casatarebeli RonisZiebebi: transformatorebis dagegmili gamoyvana muSaobidan (#2) da Catardes zeTSi gaxsnili airebis gaxSirebuli analizi (#3).

rekomendaciebi konkretuli gamocdebis prioritetul Catarebaze zeTSi gaxsnili airebis Sedegebis safuZvelze mocemulia cxrilSi 4.4

**cxrili 4.4.** zeTSi gaxsnili airebis Sedegebis safuZvelze konkretuli gamocdebis prioritetul Catarebaze rekomendaciebi.

| # | rekomendaciebi |
|---|---|
| 1 | transformatorebis dauyonebliv gamoyvana muSaobidan |
| *2* | transformatorebis dagegmili gamoyvana muSaobidan |
| *3* | Catardes zeTSi gaxsnili airebis gaxSirebuli analizi |
| 4 | SevamowmoT sorbentis mdgomareoba haersaSrobSi |
| 5 | SevamowmoT zeTis tumbos mdgomareoba |
| 6 | SevamowmoT gadadinebis SesaZlebloba (erTdroulad aviRoT zeTis sinjebi transformatorisa da gadamrTvelis avzebidan) |
| 7 | CavataroT zeTis degazacia |
| 8 | saqmis kursSi CavayenoT dawesebulebis qvedanayofi |
| 9 | gavaanalizoT wina eqspluataciis pirobebi |
| 10 | movxsnaT zeTSi gaxsnili airebis gaxSirebuli analizis kontroli |
| 11 | CavataroT zeTSi gaxsnili airebis analizis kontroli Cveulebri-vi periodulobiT |

| | |
|---|---|
| 12 | SevadaroT msgavsi transformatorebis koncentraciebs |
| 13 | SevatyobinoT qarxana-damamzadebels |
| 14 | transformatori davayenoT kontrolis qveS |
| 15 | gavzomoT gragnilebis omuri winaRoba |
| 16 | CavataroT analizi infrawiTeli teqnikis gamoyenebiT |
| 17 | gavzomoT uqmi svlis danakargebi |
| 18 | CavataroT zeTis qimiuri analizi |
| 19 | gavzomoT tgδ da izolaciis kompleqsuri gamtaroba |
| 20 | gavzomoT mokled SerTvis winaRoba |
| 21 | gavzomoT zeTis tgδ |
| 22 | vawarmooT nawilobrivi ganmuxtvis eleqtruli gazomvebi |
| 23 | vawarmooT nawilobrivi ganmuxtvis akustikurigazomvebi |
| 24 | gavzomoT izolaciis winaRoba |
| 25 | gavzomoT izolaciis winaRoba |
| 26 | CavataroT vizualuri kontroli |
| 27 | aviRoT zeTis sinjebi kontaqtorisa da transformatoris avzebidan |

zeTSi gaxsnili airebis analizi defeqtis saxis Sesaxeb ver iZleva srul garantias da praqtikulad ver warmoadgens informacias misi adgilmdebareobis Sesaxeb, amitom saWiroa Catardes sxva gamocdebic. kerZod, unda ganisazRvros airebis koncentraciis maxasiaTebeli fardoba. am maxasiaTeblis gansazRvra xdeba cxrili 2 -is fardobiTi koncentraciis striqonis monacemebis mixedviT.

D1 = 0,4 warmoadgens fardobas ( $CH_4/C_2H_4 = 2/5$ );

D2 = 6,66667 warmoadgens fardobas ($CH_4/H_2 = 2/0,3$);

D3 = ganusazRvrelia warmoadgens fardobas ($C_2H_4/C_2H_6$);

D4 = ganusazRvrelia warmoadgens fardobas ($CO_2/CO$).

nimuSSi airebis arsebobisas maTi koncentraciisa da zrdis siCqaris mniSvnelobis, aseve koncentraciis fardobiTi maxasia-Teblebis analizis dros koncentraciis maxasiaTebeli fardo-bis udidesi mTeli ricxvia 6. zusti diagnozis gansazRvrisaTvis am nomris mixedviT winaswari defeqtebis cxrili 4.5 -dan pouloben mis dasaxelebas: dabali temperaturis Termuli defeqti. amis Semdeg moiyvaneba mizezebi, romelTa Sedegia prognozirebadi defeqti [57].

- milebisa da milTaSorisi sivrcis gaWuWyianeba;
- gamaciebeli milebis dabinZureba.

amis Semdeg dgeba gamocdis oqmi.

defeqtebis ganmeorebiT SemCnevis SemTxvevaSi ismeba winaswari diagnozi cxrili 5 -Si mocemuli nakrebidan.

cxrili 4.5. defeqtebis saxeebi

| # | defeqtis saxe |
|---|---|
| 1 | zeTis daZveleba |
| 2 | nawilobrivi ganmuxtvebi energiis dabali simkvriviT |
| 3 | nawilobrivi ganmuxtvebi energiis maRali simkvriviT |
| 4 | mcire simZlavris ganmuxtvebi |
| 5 | didi simZlavris ganmuxtvebi |
| 6 | dabali temperaturis Termuli efeqti |
| 7 | dabali temperaturis diapazonSi Termuli efeqti |
| 8 | saSualo temperaturis diapazonSi Termuli efeqti |
| 9 | maRali temperaturis Termuli efeqti |

SemdgomSi defeqtis xasiaTi zustdeba cxrili 4.6 –s monacemebiT, Tu ram SeiZleba gamoiwvios aRniSnuli defeqti.

cxrili 4.6 dazustebuli defeqtebis saxeebi.

| # | defeqtis saxe |
|---|---|
| 1 | dengamtari nawilebis an ConCxis kontruqciis elemenetebis gadaxureba |
| 2 | ConCxis kontruqciis elemenetebis gadaxureba |
| 3 | myari izolaciis gadaxureba |

| | |
|---|---|
| 4 | eleqtruli ganmuxtvebi myar izolaciaSi |
| 5 | nawilobrivi ganmuxtvebi zeTSi |
| 6 | naperwkluri da rkaluri ganmuxtvebi zeTSi |
| 7 | defeqti gaciebis sistemaSi |
| 8 | zeTis daZveleba |
| 9 | defeqti gadamrTvel mowyobilobaSi |

**Semdgomi sakontrolo gazomvis periodulobis gansazRvra.** TiToeuli airis koncentraciis zrdis siCqaris Sesabamisad ganisazRv-reba drois Sualedi, romlis gasvlis Semdeg swarmoebs Semdgomi gazomva. sakontrolo gazomvis periodulobis minimaluri mniSvneloba miRebulia xuTi dRis anu 0,167 Tvis (0,167 X 30 dR = 5 dR) tolad.

qvemoT mocemulia airebis sakontrolo gazomvis Semdegi periodulobebi: $H_2$ = 2,333 Tve; $CH_4$ = 0,233 Tve; $C_2H_2$@ = 0,012 Tve; $C_2H_4$ = 0.078 Tve; $C_2H_6$ = 6,0 Tve; CO = 6,0 Tve; $CO_2$ = 0,233 Tve.

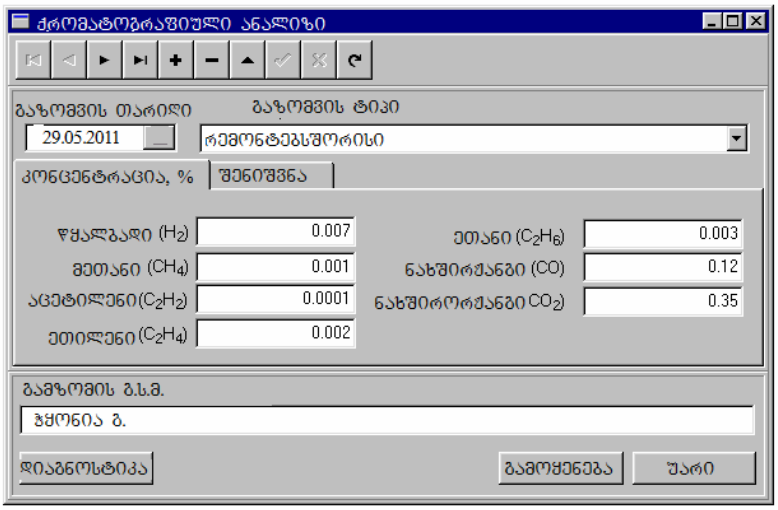
radganac T($C_2H_2$) = 0,012 < 0,167, amitom miRebulia T= 0,167 Tve. maSasadame, morigi gazomvis Catareba unda moxdes 0,167 Tvis anu 5 dRis Semdeg.

**winaswari defeqtis gansazRvra.** nimuSSi airebis arsebobisas maTi koncentraciisa da zrdis siCqaris mniSvnelobis, aseve koncentraciis fardobiTi maxasiaTeblebis analizis dros ndobis maqsimaluri koeficientis mniSvnelobam miiRo nomeri 6, radganac defeqti aRniSnuli iyo mxolod orjer.

zusti diagnozis gansazRvrisaTvis am nomris mixedviT winaswari defeqtebis cxrili 4.2-dan pouloben mis dasaxelebas: dabali temperaturis Termuli defeqti. moiyvaneba mizezebi, romelTa Sedegia prognozirebadi defeqti:

- milebisa da milTaSorisi sivrcis gaWuWyianeba;
- gamaciebeli milebis dabinZureba.

amis Semdeg dgeba gamocdis oqmi.




nax.4.1.qromatografiuli monacemebis Sesatani Sabloni.

**manqanuri formis Sevseba.** `diagnostika +" kompleqsur programaSi qromatografiuli analizis monacemebis Sesatanad saWiroa Seivsos nax.4.1-ze moyvanili Sabloni. amdros saWiroa gvaxsovdes:

- Tu airi saerTod ar arsebobs, maSin Sesabamis velSi Caiwereba 0 (nuli);
- Tu aris airis mcire raodenoba, maSin Sesabamis velSi Caiwereba 0.0000099;
- Tu airis arseboba an ar arseboba gansazRvruli ar aris, maSin Sesabamisi veli ar Seivseba.

### 4.2. eleqtromowyobilobis Tbovizoruli kontroli.

infrawiTeli Termografia warmoadgens kontrolis damxmare saSualebas, gvexmareba transformatorSi airwarmoqmnis arsebobisas SevafasoT magnitogamtarSi defeqtis warmoqmnis zona, xolo saqarxno dokumentaciis arsebobisas SevaviwrovoT defeqtis moZebnis adgili.

**transformatoris avzSi ganlagebuli defeqturi kvanZebis infrawiTeli diagnostika. transformatoris avzSi siTbos gamoyofis wyaroebi.** transformatoris avzSi siTbos gamoyofis wyaroebia Semdegi kvanZebi:

- magnitogamtari;

- gragnilebi;

- transformatoris masiuri metalis nawilebi, romlebSic siTbo gamoiyofa fantvis nakadebis mier aRZruli grigaluri denebiT gamowveuli damatebiTi danakargebis gamo;

- Semyvanebis dengamtari nawilebi da maTi kontaqtebi;

- ganStoebebi da maTi SeerTebebi gragnilTan da SemyvanTan;

- Zabvis qveS regulirebis gadamrTvelis kontaqtebi.

**magnitogamtaridan da gragnilebidan transformatoris avzze siTbos gadacemis xasiaTi.**

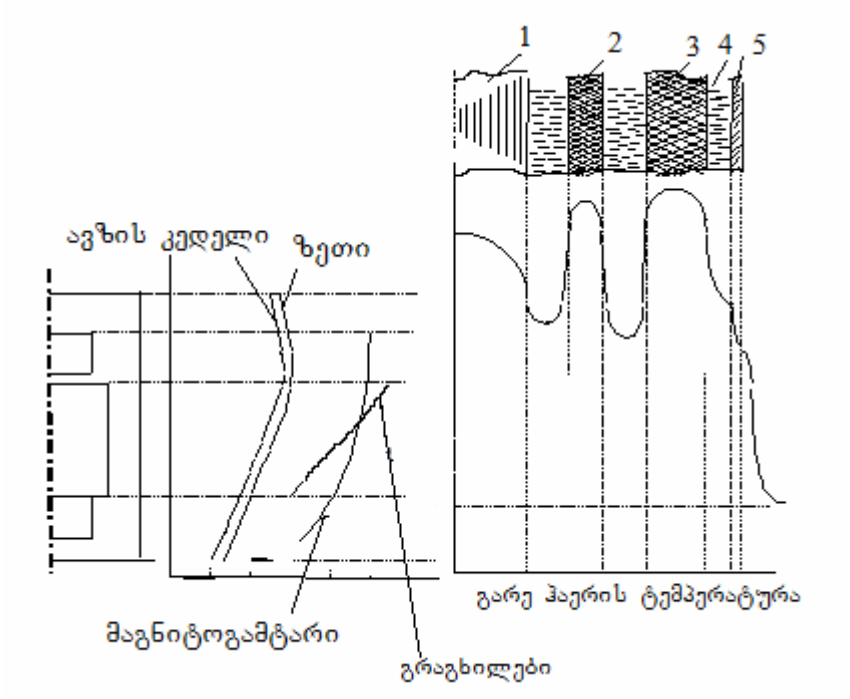
TbovizoriT transformatoris Sinagani Tburi mdgomareobis Sefasebisas saWiroa angariSi gavuwioT magnitogamtaridan da gragnile-bidan siTbos gadacemis xasiaTs (nax.4.2).

[58]-is Tanaxmad transformatoris nominaluri datvirTvis dros zeTis zeda fenebis temperatura ar unda iyos cxrili 4.7-Si naCveneb temperaturaze meti, Tu qarxana-damamzadeblis mier mocemuli ar aris sxva temperaturebi.

cxrili 4.7. zeTis zeda fenebis dasaSvebi temperatura

| | |
|---|---|
| transformatorebisa da reaqtorebis zeTiT gacieba SeberviTa da zeTis iZulebiTi cirkulaciiT | $75^0$C |
| transformatorebisa da reaqtorebis zeTiT bunebrivi gaciebiT, SeberviTa da zeTis bunebrivi cirkulaciiT | $95^0$C |
| transformatorebisa zeTiTa da wyliT gacieba, zeTis iZulebiTi cirkulaciiT | $70^0$C |

[59]-is Tanaxmad transformatoris mTel simaRleze maqsimalur da minimalur temperaturaTa Soris sxvaobam SeiZleba miaRwios 20-35$^0$C-s




nax.4.2. temperaturis cvlileba transformatorSi: a-simaRleze;b-kveTis gaswvriv. 1- Rero;2,3- dabali da maRali Zabvis gragnilebi; 4-zeTi; avzis kedeli.

**transformatoris avzis Tburi veli.**

transformatoris avzis zedapiris Termogramebi gadaiReba:

- gragnilebis ganStoebebis ganlagebis adgilebSi;
- transformatoris avzis simaRleze;
- kidura fazebis mimarT;
- avzis zarxufis damagrebis adgilebSi.

avzis zedapiris temperaturis gradientis mniSvnelobebisa da maTi adgilmdebareobis mixedviT, transformatoris teqnologiuri dokumentaciis daxmarebiT fasdeba masSi SesaZlo defeqtebi.

250 mva da meti simZlavris transformatorebisa da avtotransformatorebisaTvis rekomendirebulia eqspluataciaSi Seyvanis dros gadaviRoT avzis Tburi velis suraTi.

**gragnilebis defeqtebi.** modelebze Catarebulma eqsperimentebma aCvena,rom infrawiTeli kontrolis dros transformatoris avzSi SeiZleba gamovlindes lokaluri gaxurebebi, romlebic gamowveulia:

- gragnilebis calkeuli koWebis adgilobrivi gaxurebebiT;

- gragnilebis ganStoebebis kontaqturi SeerTebebis gadaxurebebiT;

- zeTis damdgari zonebis gamokvleviT, romelic gamowveulia xviaTa qaRaldis izolaciis gajirjvebiT, Slamis warmoqmniT an konstruqciul angariSSi SecdomiT.

**magnitogamtaris Camiwebis sistemebis defeqtebi.** transformatoris fazebis Termografiulma gamokvlevam transformatoris fazebis avzze gamoavlina temperaturuli anomaliebi, kerZod avzis zarxufis qveda gasarTis dasamagrebeli didi raodenobis WanWikebis gaxureba. transformatoris avzis gaxsnam gamoavlina Semdegi defeqtebi:

- magnitogamtaris qveda konsolisa da Sveleris SeerTebis adgilze firfitebis gadaxurebisagan gamuqeba;

- transformatoris saregulirebeli Reros raionSi avzis Zros mimarTveli kotas dabali Zabvis konsolTan Camiweba;

- sayelurebis, firfitebisa da WanWikebis gamuqeba da nawilobrivi gadnoba gaxurebisagan.

magnitogamtaris Camiwebis sqemis megaommetriT Semowmebam aCvena:

- magnitogamtar-avzis ubanze izolaciis winaRoba nulis tolia;

- magnitogamtaris paketebs Soris izolaciis winaRoba Seadgens 6 omidan 5 kiloomamde.

**infrawiTeli diagnostikis meTodi zeTSevsebuli SemyvanebisaTvis.** Tbovizorebis daxmarebiT Semyvanebis mdgomareobis SefasebisaTvis saWiroa gaTvaliswinebuli iqnes is faqtorebi, romlebic gavlenas axdenen infrawiTel kontrolze:

- mzis radiacia;

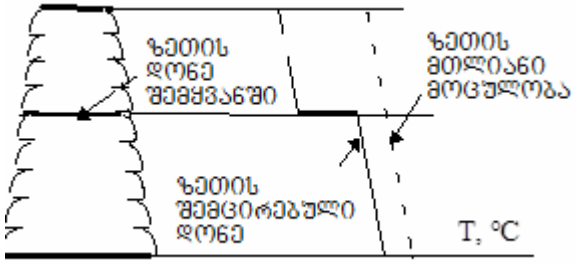
- faifuris safaris zedapiris lokaluri gaWuWyinebebi;

- haeris Tburi nakadi, romlebic moedineba transformatoris saxuravidan da Semyvanebidan.

**gareSe gamtarebis Semyvanebis momWerebTan mierTebis adgilebis gaxurebebi**. dasaSvebi temperatura tolia [60]: $t_{das} = 90^0C$, roca haeris temperatura $t_{haer} = 40^0C$. e.i,. dasaSvebia temperaturaTa sxvaoba $\Delta t = 50^0C$.

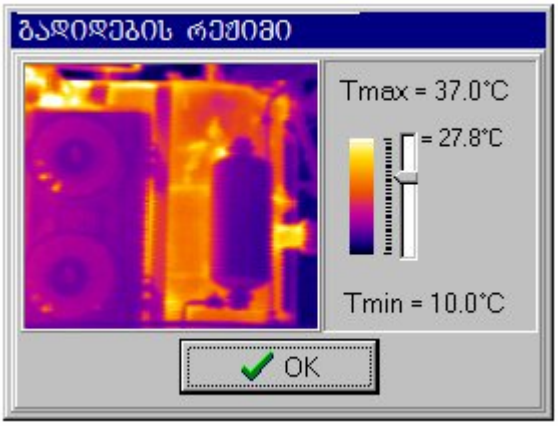
**SemyvanebSi zeTis donis dacema**. SemyvanSi zeTis sruli moculobis arsebobis dros adgili aqvs temperaturis gradientis mdore dacemas transformatoris avzidan Semyvanis safarToebe lisaken. winaaRmdeg SemTxvebaSi SeiniSneba temperaturis gradientis naxtomi.

nax.4.3-ze mocemulia defeqturi Semyvanis Termoprofili.




nax.4.3. Semyvanis Termoprofili daweuli zeTis doniT.

Tbovizoris fanjris saerTo saxe gadidebul reJimSi mocemulia nax.4.4-ze.




nax.4.4. transformatoris TbovizoriT dasaTvalierebeli fanjara.

D`daTvalierebis" reJimi saSualebas iZleva ganvsazRvroT temperatura transformatoris zedapiris nebismier wertilSi. amisaTvis sakmarisia mxolod davawkapunoT mausis marcxena klaviSi saintereso temperaturis wertilSi. mocemuli fanjara

saSualebas iZleva aseve vaCvenoT mocemuli temperaturis yvela wertili. amisaTvis sakmarisia davawkapunoT mausis marcxena klaviSi fanjridan marjvena ferad zolze. am dros mocemuli temperaturis yvela wertili gamoiyofa mwvane feriT, xolo temperaturis maCvenebeli gviCvenebs am wertilebis namdvil temperaturas.

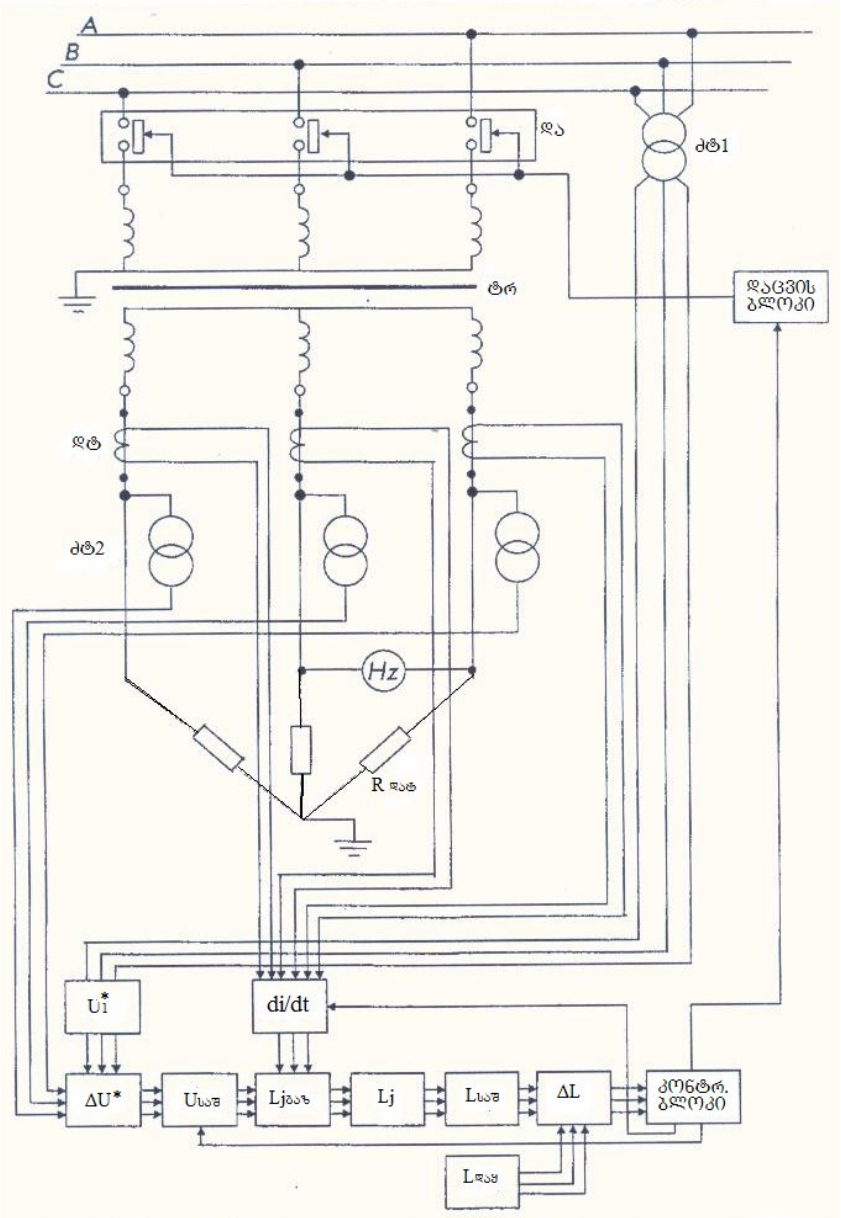
### K4.3. transformatoris gragnilebis dazianebis gansazRvra induqciuri winaRobis kontroliT

infrawiTeli diagnostikis saSualebebis daxmarebiT Tbovizoruli kontrolis meTods Zaluri transformatorebis gare elementebis (maRalvoltiani Semyvanebis, ganmmuxtvelebis, gadamrTvelebis, gacivebis sistemebisa da sxvaTa) mdgomareobis Sesaxeb SeuZlia moitanos mravali sasargeblo informacia, magram igi iTvleba irib meTodaT, romelic ar iZleva transformatoris avzis kedlebisa da didi moculobis satransformatoro zeTis qveSMdafaruli aqtiuri nawils mdgomareobis Sesaxeb srul informacias. Ggarda amisa zemoTCamoTvlili meTodebi yovelTvis ar aris efeqturi mokled SerTvis dros Zalovani transformatorebis gragnilebSi narCeni deformaciis aRZvris SeTxvevaSi, romlebic xdeba myisierad da ar toveben dros diagnostikuri gazomvebis Sedegebis analizisaTvis da transformatoris dazianebis Tavidan acilebis an momavali remontis masStabebis Semcirebis mizniT ver uzrunvelyofen rac SeiZleba swrafad moxdes misi gamorTva.

Zaluri transformatoris gragnilebSi xviaTaSorisi mokled SerTvis Sedegad gamowveuli gragnilebis deformaciis mimarT yvelaze ufro mgrZnobiarea induqciurobis parametri. aseTi transformatorebis gragnilebSi sawyisi deformaciebis aRZvrisas da xviaTaSorisi mokled SerTvis SemTxvevaSi periodidan periodamde xdeba induqciurobis ganviTarebadi gazrda an Semcireba, romelsac Tan axlavs sakontrolo transformatoris gragnilebis Seuqcevadi rRveva. Mam MmeTodis

bazaze Seqmnilia Zaluri transformatorebis parametrebis kontrolis sainformacio - sazomi sistema, romelic SeiZleba gamoyenebuli iqnes mokled SerTvis cdebisa da eqspluataciis dros qselidan gamourTvelad Zaluri transformatorebis gragnilebis mdgomareobis operatiuli kontrolisaTvis.

induqciurobis Secvlis SemTxvevaSi Aam dros kontrolis blokidan marTvis blokze miewodeba signali, romelic formirdeba **da** damcveli amorTvis signalad (nax.4.5).




Nnax.4.5. eqspluataciis procesSi qselidan gamourTvelad Zaluri transformatoris gragnilis kontrolis sainformacio-sazomi sistemis sqema.

sainformacio-sazomi sistema saWiroa gamoyenebuli iqnes im reJimebisagan swrafmoqmed dacvasTan kavSirSi, romelnic aRiZvrebian Zalovan transformatorebis gragnilebSi mokled SerTvis gamo maTSi eleqtrodinamiuri Zalvebisagan dazianebebisa da narCeni deformaciis Sedegad parametrebis cvlilebiT.

sainformacio - sazomi sistema muSaobs Semdegnairad: Zaluri transformatorebis gragnilebis mdgomareobis uwyveti kontroli uzrunvelyofilia induqciurobis bazisuri mniSvnelobidan gadaxris mudmivi kontroliT. Binduqciurobis bazisuri mniSvneloba aiReba dayenebis blokidan. sakontrolo samfaza **tr** Zaluri transformatoris muSaobis dros samfaza $R_{dat}$ aqtiur datvirTvaze sazomi gardamqmnelis - maRalvoltiani Zabvis transformatoris **Zt1** daxmarebiT izomeba pirveladi $U_1$ Zabvis mniSvneloba. Ggardamqmnelidan signali miewodeba pirveladi Zabvis meoreul Zabvaze damyvan $U'_1$ bloks, sadac gamoiTvleba meoreul Zabvaze dayvanili pirveladi Zabva:

$$U'_1 = U_1/K_t \qquad (4.1)$$

sadac $K_t$ – Zaluri transformatoris koeficientis mocemuli cnobili mniSvnelobaa.

sistemis Sesavalze meoreuli Zabvis gardamqmnelebidan – **Zt2** Zabvis transformatorebidan da $U'_1$ blokis gamosasvlelidan miewodeba signale-bi. Zabvebis sxvaobis gamoTvlis blokSi meoreul Zabvaze dayvanili Zabvebis sxvaoba gamoiTvleba formuliT:

$$\Delta U'_1 = U'_1 - U_2 \qquad (4.2),$$

sadac $U_2$ aris **Zt2** gardamqmnelis meoreuli Zabvis mniSvneloba.

Zabvis saSualo mniSvnelobis gamoTvlis blokSi $U'_{saS}$ angariSi swarmoebs drois mocemul intervalSi:

$$U'_{saS.} = [U'n(t_2) + U'n(t_1)]/2 \qquad (4.3),$$

sadac $U'n$ aris transformatorze Zabvebis dayvanil mniSvnelobaTa sxvaoba; $t_1$ da $t_2$ –danawilebis intervalebis droebiTi sazRvrebi.

Ddenis warmoebuli gamoTvlis blokSi ganisazRvreba dens nazrdi drois mocemul intervalSi:

$$di/dt = [i_j(t_2) + i_j(t_1)]/(t_2-t_1) \qquad (4.4),$$

sadac $i_n$ aris sakontrolo transformatoris meoreul gragnilSi denis mniSvneloba, romelic izomeba denis gardamqnelebiT – **dt** denis transformatorebiT.

induqciurobis gaangariSebis blokSi $L_{jgaz}$ .gamoiTvleba drois mocemul intervalSi induqciurobis myisa mniSvneloba:

$$L_{jgaz.} = U'_{saS}/di/dt \qquad (4.5).$$

Aamis Semdeg induqciurobis gazomili myisa mniSvneloba miewodeba induqciurobis nominalur sixSireze dayvanis bloks da gaiangariSeba induqciurobis nominalur sixSireze dayvanili mniSvneloba:

$$L_j = L_{jgaz} \cdot f_{gaz}/f_{nom.} \qquad ^(4.6),$$

sadac $f_{gaz}$ aris gazomili sixSire,; $f_{nom.}$ Nnominaluri sixSire (50hc). Semdeg blokSi gaiangariSeba induqciurobis saSualo mniSvneloba TiToeuli periodis ganmavlobaSi:

$$L_{saS} = \sum_{n=1}^{N} \frac{Ln}{N} \qquad (4.7),$$

sadac N aris intervalebis danawilebis ricxvi.

amis Semdeg gadaxris gamoTvlis blokSi periodis ganavlobaSi miRebuli $L_{saS}$ mniSvneloba Seedareba dayenebis $L_0$ mniSvnelobas da ganisazRvreba maTi gansxvaveba:

$$\Delta L = (L_{saS} - L_0)\ X\ 100\ \%\ /L_0 \qquad (4.8),$$

sadac $L_0$ – transformatoris induqciurobis dayenebuli mniSvnelobaa, romelic ganisazRvreba angariSiTa da winaswari eqsperimentis SedegebiT.

# 3. დასკვნა

Catarebuli gamokvlevebis safuZvelze miRebulia Semdegi Sedegebi:

1. dadgenilia, rom dReisaTvis saqarTvelos elmomaragebis sistemaSi Zaluri transformatorebis mniSvnelovanma nawilma amowura Tavisi muSaobis resursi. Qqveynis ekonomiuri situacia, agreTve transformatorebis saerTo raodenobis didi ricxvi ar iZleva uaxloes xanSi maTi Secvlis saSualebas. Aamitom transformatorebis drouli diagnostika metad aqtualuri Temaa.
2. saqarTvelos saxelmwifo eleqtrosistemaSi 110-500 kv Zabvis qvesadgurebis, Ria da daxuruli gamanawilebeli mowyobilobebis saxeobebis mixedviT warmodgenili mtyunebebis, uwesivrobisa da defeqtebis gamovlenis jamuri ganawilebis analizidan gamomdinare dadgenilia, rom mowyobilobis izolaciis klasis zrdasTan erTad arsebobs mtyunebaTa zrdis tendencia. gamovlenili uwesivrobebisa da defeqtebis didi nawili pirvel rigSi miekuTvneba eqspluataciaSi Seyvanil axali tipis mowyobilobebs, rac gamowveulia maTi damzadebis xarisxiT
3. dadgenilia, rom principul problemas warmoadgens koncefciis Teoriuli uzrunvelyofis arsebiTi CamorCena diagnostikis Tanamedrove saSualebebisa da informaciuli teqnologiebis miRwevebis realuri SesaZleblobebisagan.
4. dadgenilia, rom teqnikurad dasabuTebuli diagnozis dasma SesaZlebelia mxolod srulyofili informaciis pirobebis statistikuri monacemebis Sekrebis, gare daTvalierebisa da specialuri xelsawyoebis saSualebiT Catarebuli eqsperimentuli gamokvlevebis Sedegad;
5. dadgenilia, rom diagnostikis Tanamedrove meTodebi da teqnikuri saSualebebi energosistemebSi saSualebas ar iZlevian ZviradRirebuli eleqtromomowyobilobis qseli-

dan gamorTvisa da gaxsnis gareSe gamovlenili iqnas calkeuli elementebis mmuSaobis reJimebi. amasTan dakavSirebiT iweleba eletromowyobilobis remontSi gadayvanis dro, ixarjeba operatiuloba da izrdeba avariuli reJimebis gazrdis albaToba.

6. dadgenilia, rom udaod aqtualuri xdeba kontrolis iseTi axali meTodebis damuSaveba, romlebiTac transformatoris gaxsnis gareSe moxdeba misTvis damaxasiaTebeli sxvadasxva parametrisa da monacemis gazomva, defeqtebis aRmoCena da aRmofxvra.
7. Ddadgenilia, rom eleqtromowyobilobaTa diagnostikis sferoSi mimdinare samecniero-kvleviT samuSaoebSi kompiuteris farTod gamoyenebam aucilebeli gaxada maTematikur modelirebasTan erTad eleqtruli wredebis Teoriis sferoSi axali Teoriuli midgomebis damuSaveba da miRebuli Sedegebis WeSmaritebis Sefaseba.
8. damtkicebulia Tanamedrove pirobebSi energoefeqturi RonisZiebebis gatarebisaTvis samfaza transformatoris maTematikuri modelis saWiroeba.
9. datvirTvis reJimSi samfaza transformatoris Sesabamisi gantolebata sistemis amosaxsnelad Sedgenili iqna blok-sqema, romlis safuZvelzec SesaZlebelia Sedges kompiuteruli programa optimaluri eleqtruli da magnituri parametrebis SesarCevad.
10. Zaluri transformatorSi ganviTarebadi defeqtis dadgenis mizniT SemuSavebuli iqna specialuri algoriTmi, romelic saSualebas iZleva sakmao sizustiT ganvsazRvroT ganviTarebadi defeqtis saxe, misi gamomwvevi mizezi da mosalodneli Sedegi.

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