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ELECTROENERGETICS, ELECTROTECHNICS, ELECTROMECHANICS + CONTROL

Scientific - Industrial Journal

Dear Readers,

The consistent, solid and systematic development of the largest energy system of the South Caucasus founded at the 60^{th} in the last century during the leadership of our national leader Heydar Aliyev. The power sector is rapidly developing as a structural division of the Azerbaijani economy. Electricity being part of the energetic is also considers preparation of the high-efficient technologies, fundamental researches and applying of the obtained results to the production.

The publication of the "Electricity, power engineering, electromechanics +control" journal founded by the initiative of "Azerenerji" JSC and "Azerbaijan Scientific-Research and Design-Prospecting Power Engineering Institute" and considering agitation of the working out methodologies of the electricity development perspectives will play significant role in delivering the achived science-practical results in this field to the attention of local and international power engineers. I appreciate the labor of leadership, professor staff, as well as engineering and scientific-technical employees of the "Azerbaijan Scientific-Research and Design-Projecting Power Engineering Institute" in the development of science of power-engineering, increasing of personnel potential, agitation and applying of science results and wish success to the editorial staff in their difficult and responsible work.

Etibar Pirverdiyev
President of "Azerenerji" JSC

Dear power engineers,

National leader of Azerbaijan Heydar Aliyev had repeatedly noted the special role of the electric power field in resolving social problems. Since the second half of the last century the establishment of the South Caucasus' dominant energy system has started. Nowadays successful development of the electric power field is being continued by President honourable Ilham Aliyev. After ratification of the "National Strategy on development of science in Azerbaijan Republic in 2009-2015" and "State Program on the implementation of the National Strategy on development of science in 2009-2015 in the Azerbaijan Republic" important issues on science development were put before power engineers. As key positions arising from the State Program issues such as the preparation of scientific personnel, improvement of the material-technical base of science has been marked. "Azerbaijan Scientific-Research and Design-Prospecting Power Engineering Institute" has always been one of the leading institute of the republic and is the first taking part in the ANAS organization and currently occupies a leading position in preparation of personnel on electricity field. I approve the publication of the "Electricity, electrical engineering, electromechanics + control" journal that considers to deliver fundamental scientific results dedicated to the development of the electricity, applying works to the energy society of the republic, as well as the world's leading science centers. I wish success to the editorial staff in implementation of such a responsible and glorious work.

prof. Arif Mehdiyev
Active Member of the Azerbaijan National
Academy of Sciences
Chairman of the Supreme Attesting Commission

Jour. EEEC, V.1, N.1, 2010, p.5

Dear Colleagues,

In the last years our country has turned to the leader state of the region and one of the main energy safety guarantors of the Europe in the result of perfect strategy implemented by the initiative and administration of the honourable President Ilham Aliyev. We are very glad to represent the first issue of a new journal initiated and founded by the "Azerenerji" JSC and "Azerbaijan Scientific-Research and Design-Prospecting Power Engineering Institute" "Electricity, electrical engineering, electromechanics + control" devoted to the sustainable development of electricity sector which is considered one of the leading areas of the country's economy.The journal is initially planned to be published two times in a year and the solution of important problems on power engineering will be reflected in it.The main purpose of journal is the publication of high-level articles dedicated to electric power systems, power stations, substations and their main equipments, electrotechnical complexes, automation and management means, the development of alternative energy sources and their activity. In the electricity development conditions the working out of the economic principles and methods of the energy security, energy efficiency issues are being intensively developed all over the world. At the same time application of modern innovative technologies, estimation of the alternative energy sources role, development of the economic aspects of the energy systems, assessment of the energy systems in the field of interstate cooperation condition and its legal base are important issues awaiting their solution.The topics will also cover systems analysis, management and information software, automation and technological processes management and their modeling, as well as electrical and heating appliances, electrical machinery and apparatus, electric drivers, high-voltage equipment, electrotechnical materials, development of the bases of economic sector electricity supply. Original research results, the modern applying state and conditions of the science-research means in this or other areas will be delivered to the attention of local and international experts. Information about materials of the symposiums, conferences and seminars held in the area of power engineering inside republic and internationally, as well as monographs, discussions, opinions will also be printed in the journal. Congratulations to everybody who contributed to the publishing of the journal. We wish successes to editorial staff in their future work. We invite the potential authors of the international commitity to publish scientific articles in the journal of " Electricity, electrical engineering, electromechanics + control".

Professor Nurali Yusifbayli
Director of the "Azerbaijan Scientific-Research and Design-Prospecting Power Engineering Institute" LTD

Jour. EEEC, V.1, N.1, 2010, pp.6-14

ABOUT READINESS OF AZERBAIJAN REPUBLIC POWER SYSTEM ON REALIZATION OF "POWER BRIDGE" AZERBAIJAN-GEORGIA-TURKEY PROJECT

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ABSTRACT. Technical and economic condition and development indicators of Azerbaijan Republic power system are considered in a context of effective functioning requirements of associations in the conditions of synchronous parallel work on system interconnection. The problem urgency depends on prospects of Azerbaijan-Georgia-Turkey "Power Bridge" power system establishment.

Keywords: The Power Bridge, A Power System, Integration, Power Efficiency, Reliability.

1. Introduction

The interstate integration of power systems (PS) for parallel work has more than semicentenial history, actually, PS by association for parallel work of separate power plants, their territorial, regional, international, and also intercontinental associations.

Process of PS integration is caused by variety of the objective reasons and factors, among them are: frequency, power, regime, structural, ecological, etc. effects [9,11]. Practically all of them are reduced to decrease in production costs, transport and electric power distribution. Thus not less important factor is maintenance of social and political stability of the countries encompassed by united power system (UPS).

Nowadays in the world a number of large PS operates. Among them: in Europe ENSTO-E, arisen in 2009 by connection of Western and Central European PA's (ATSOL, BALTSO, ETSO, NORDEL, UCTE, UKTSOL); in the North America - the USA, Canada, Mexico ("EASTEN GRID", "WEST GRID", "TEXOL GRIG"; in the South America "MERCOSOUR"; in Africa ELTM, EIJST; in Asia EPA/OPA, CAPS, EIJLS. In the big territory of Russia operates IPS/UPS which covers also some PS of the North Asian countries.

Integration process proceeds, covering the increasing number of the countries and their PS. So there are projects of African IPG set up (on the basis of PS CAPP, WAPP, EAPP, SAPP) [2,10,12], the Latin American association SIEPAC [4]. In Asia on the basis of the countries ES, Southern (SA), Southeast (SEA), Northeast (NEA) and Southwest (SWA) Asia there is a prospect of establishment Trans-Asiatic PS. The great importance is given to creation of the UPS countries pool - the river Mekong-GMS [3]. The point of issue is creation of Eurasian UPS where IPS/UPS and NEA take essential role [1].

Every PS or UPS has its place in electro power globalization strategy that equally concerns Azerbaijan Republic (AR) PS [8,7].

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2. A place of AR PS in UPS integration strategy

AR PS takes a special place on "an electric map" of South Caucasian region. The geographical position, existence of developed electric network of 500-330-220 kV allows it to enter in an electric bond as "North-South" and "East-West". More than 20 years, interstate interconnections (II) such as the Yashma (Azerbaijan) - Derbent (RF) of 330 kV, II - Akstafa (Azerbaijan) - Gardabani (Georgia) II of 330 kV operate. Development of II with Iran PS on pressure of 220-330 kV have been received (Fig.1).

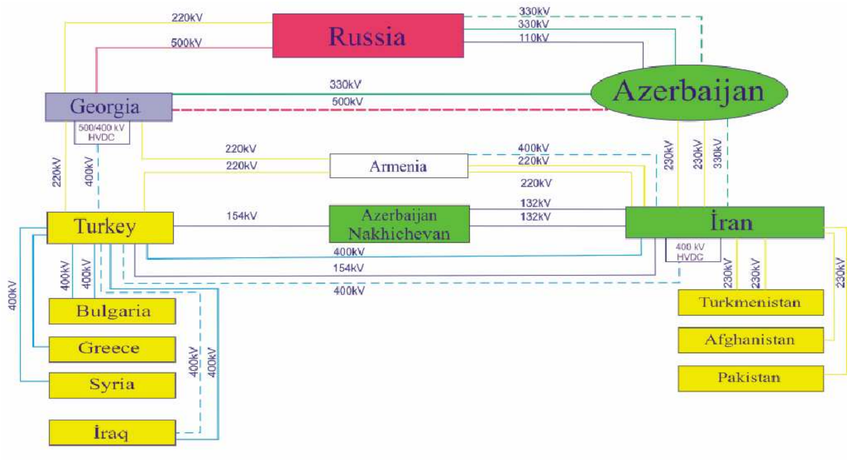

Figure 1. Development of II with Iran PS on pressure of 220-330 kV.

The Nakhichevan Autonomous Republic not having electric communications with AR, has electric communication with Turkey PS on pressure of 154 kV. Absence of direct geographical borders with Turkey puts forward on the agenda necessity of Azerbaijan - Georgia-Turkey "Power bridge" set up (AGT PB). Importance of this project realization in a context of intercontinental association is defined by that Turkey PS already has electric communications with PS of Greece, Bulgaria, Romania (Europe), with Iran, Iraq, Syria (Near East), and Iran PS - with ES of Pakistan, Turkmenistan, Afghanistan (Asia) and further. Thus, establishment of AGT PB can realize a role of AR PS in an "East-West" and "North-South" electric bond.

3. The problems solved at a stage of UPS substantiation

The substantiation and estimation of efficiency of interstate transmission lines creation demands the decision of a complex technical and power economic problems. Among them are: power possibilities of UPS, reservation, ways of realization of electric communications and their throughputs, a kind of a current and classes of pressure, possibility of maintenance of an electrical supply reliability at level of the modern standard 0,9996, adjusting abilities on frequency and overflows of capacity, suppression possibility low-frequency electromechanical fluctuations on II, levels of static and dynamic stability, etc. The latest is rather actual, since the statistics of breakdown susceptibility in UPS with mass switching-off of consumers inevitably grows. It is necessary to add here many questions from economy and ecology sphere. On the basis of such complex analysis results conclusions about efficiency of association are made.

From these positions possibilities of AR PS, its readiness to meet requirements to parallel work in UPS are more low considered.

4. A condition and immediate prospects of AR PS development

AR PS has almost 40-year-old experience of synchronous work in Transcaucasia UPS and the former USSR PS. Throughout the history was dynamically developing and plays a dominating role in the South Caucasian region.

Periods of crisis and after crisis reanimation have passed, and now electric power industry is in conditions of a sustainable development of AR economy [13].

At the basis of generating capacities development was put their diversification and distribution which not only has deduced system on level almost 6500 Vt - the established capacity ($\approx$ 5000 MVt in 1995) and has received its surplus for export, but also has received positive dynamics of variety of indicators which characterize PS efficiency, its ability to be the reliable partner in UPS.

Till 2000 year in PS only 2 types of generating installations - steam-turbine (ST) with rather low efficiency (30 %) and hydro-turbine (HT) installations carried out electric power production (tab.1).

Table 1. Dynamics of structure of generating installations.

	1995	2002	2006	2009	2010	2015
TPP	4124 82,9	4124 73,2	3450 64,7	3450 51,8	2640 39,8	2690 29,9
GPP	-	107 1,9	107 2,0	107 1,6	107 1,6	107 1,2
GTCC	-	400 7,1	400 7,5	925 13,9	1705 25,7	2405 26,7
Hydro PP	828,5 16,8	982,6 17,4	1025 19,3	1025 15,4	1025 15,5	1450 16,1
Engine PP	-	-	348 6,5	875 17,3	875 17,4	1255 13,9
Small HPP	19,4 0,4	19,4 0,4	5	-	-	700 7,8
Wind PP	-	-	-	-	-	400 4,4
Σ	4972	5633	5330	6382	7182	9007

During 10 years the system included gas-turbine installations (GT)-2x55MVt, ST installations - 925 MVt, diesel installations (DI)-874 MVt, and the last (6 modular power plants (PP)) - within the regions development program following a principle of the distributed generation that has allowed to finish in the shortest way in many cases the electric power to the end user and to lower, thus, capacity loss in transferring network, in 2011 it is expected input STPP (780 MVt), and to 2015 year - a network of small HPP and Wind PP with the general development of 3,5 and 4,5 billion kVt/h in a year, accordingly. On figure 2 growth of electric energy development is shown.

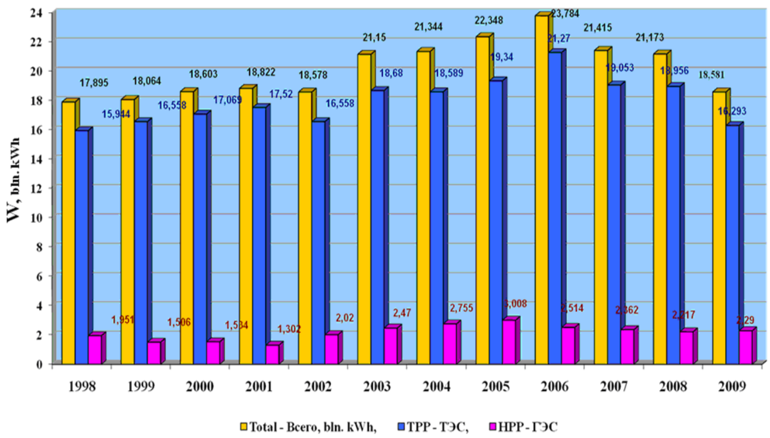

Figure 2. Trend of power production.

Prominent feature - after large-scale introduction power saving measures in sphere of production and consumption of electric energy (introduction about 500 thousand intellectual systems of the account and the electric power control), its consumption has decreased and for the first time for the 20-year there has been a positive balance of electric energy (fig. 3).

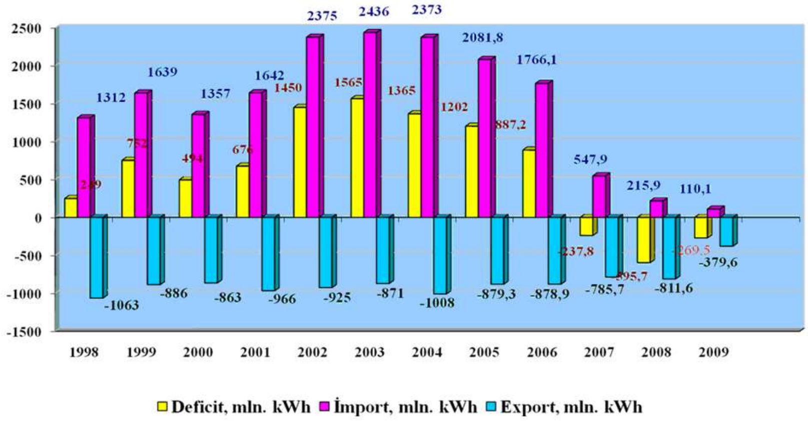

Figure 3. Trend of energy exchange with neighboring countries.

Thanks to the realized projects which total cost is more than 2 billion euro, already now PS is superfluous, its export potential makes 5-6 billion kVt/h, and in the near future will increase by 2-3 billion kVt/h.

In the presence of superfluous capacity requirements of reliability, survivability, profitability and ecological compatibility should be satisfied.

Some of indicators of these requirements, characterizing AR PS are drawn in table 2.

Apparently on the resulted important indicators (power safety of the 1-4 item, ecological compatibility of the 5-9 item, profitability of the 10-14 item), takes place of positive dynamics.

One of the basic problems at the organization of synchronous parallel work is maintenance of frequency and exchange of capacity overflows. Performance accepted in UPS norms and rules, frequency and capacity regulation is the integral condition of its reliable functioning. In connection with these PS, entering into association should possess sufficient possibilities of regulation of these parameters.

Frequency regulators on new thermal blocks of AR PS (SQTPP 400 MVt "Mitsubishi", GTI 552 MVt, "Alston", SQTPP-525 MVt "Siemens"), are more preferable. In particular, on SQT-400 MVt block three modes of regulation are provided: "without a regulator", "without a regulator with tracing of restriction of loading", "restrictions of loading with automatic tracing of a regulator". Introduction in AR PS systems SCADA allows useful usage of adjusting possibilities of blocks. In a figure 4 there is presented the algorithm of automatic generation control (AGC) carrying out checking, distribution and the control of capacity generation.

Table 2.Dynamics of technical-economical and other indicators of energy safety

	Indicators	**Unit of measurements**	**1995**	**2000**	**2005**	**2006**	**2007**	**2008**	**2009**
1	Portion of most powerful plant	%	48,3	46,4	45,3	43,2	42,4	40,2	36,4
2	Portion of mast powerful unit in whole installed capacity power system	%	6,0	5,8	5,7	7,2	7,0	6,7	6,3
3	Average capacity of PP	MW	832	867	800	556	517	470	353
4	Average capacity of unit	MW	192	200	186,7	73	79	67	52
5	Oxide –sulphur SO2	thsd.t	4,0	39,7	11,5	9,4	6,4	3,4	0,97
6	Nitric – oxide NO2	thsd.t	38,9	40,8	19,6	22,5	16,5	13,7	12,5
7	Outgoing ash	thsd.t	16,9	16,4	0,5	0,4	0,3	0,1	0,041
8	Carbonic acid CO2	thsd.t	15389	15657	16332	17487	14461	13815	11378
9	Oxide carbon CO	thsd.t	-	-	0,4	1,2	2,99	2,36	4,35
10	Fuel rate	get/kW	385	411	379	368	353	346	327,9
11	Used full ratio gas/heasy oil	%	18,9 81,1	22,6 77,4	67 33	76,5 23,5	78,9 21,1	90,4 9,6	96,6 4,4
12	Share units talking part in satisfying peak demand	-	17,0	19,2	18,0	24,6	26,0	29,8	15,3
13	Share of unite distributed generation	-	-	-	-	6,3	8,0	12,6	17,3
14	Efficient Power System	%	31,9	29,9	32,4	33,4	34,8	35,5	37,5

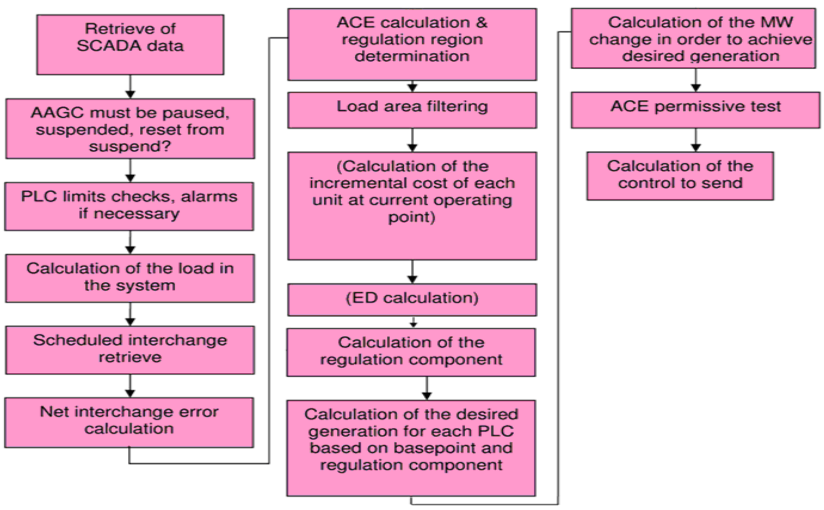

Figure 4. Algorithm of automatic generation control.

Basic purpose of AGC is realization of the continuous control over frequency and contractual overflows of capacity and secondary regulation.

AGC in real time obtains given signals from SCADA system which are sent on power station (if SCADA database is active). Calculation of operating influences is carried out by block "MONITOR" in AGC, thus degree of each station's participation is defined due to actual cost, an actual limit of regulation, degree of tolerance, etc. Thus the control error on interchange between countries is also calculated under the following formula:

In the Tie line Bias Control mode the ACE is calculated as:

$$ACE = (I_{actual} + I_{various} - I_{schledule} - I_{Gifset}) + 10B\,(f_{actual} - f_{schledule} - f_{Gifset})$$

I_{actual} Interchange between Azerenerji and all the other countries (Russia, Georgia, Iran and Turkey)

$I_{various}$ Connection between non telemetred operating areas, or measurement errors.

$I_{schledule}$ Total scheduled interchange at present time with all the other countries (Russia, Georgia, Iran and Turkey)

I_{Gifset} Correction on the accumulated error on interchange. It is either manual or automatic

B Frequency bias in MW / 0.1Hz

f_{actual} Measured frequency

$f_{schledule}$ Scheduled frequency

f_{Gifset} Correction on frequency , for the accumulated time error. It is either manual (the operator enters *fGjfset* in Hz), or automatic.

Already now in synchronous machines of AR PS operate ACE of various types: five-channel APE of strong action, UNITROL-5000, UNITROL-1000 type regulators, etc. Distinction of structures and channels of regulation do not cause a negative effect in damping of electromechanical fluctuations. The researches spent in [6, 5] show, that options of these regulators can be corrected from a condition of the best indicator maintenance of a dominating component of electromechanical low-frequency fluctuation.

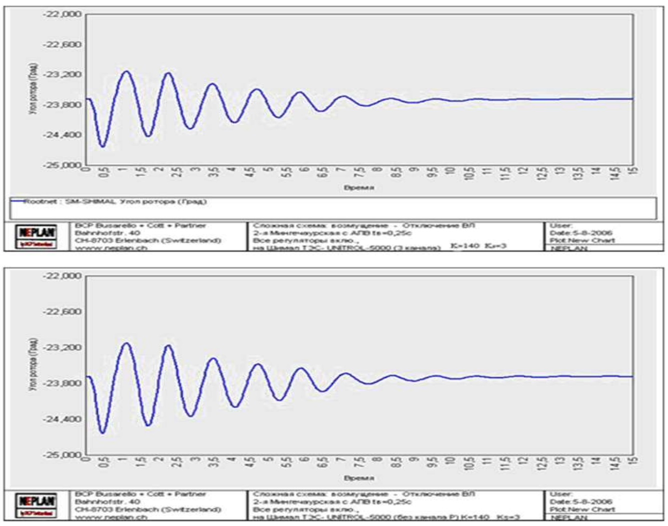

Figure 5. Difficult scheme AVR - Strong actions Kou=50 Kf=11
AVR+PSS K=140 Ks=3
a)AVR+PSS 3 channel (U,P,f)
b)AVR+PSS 2 channel (U,f)

On figure 5 oscillatory changes of a shift corner between vectors ENP of rotors of synchronous machines “Azerbaijan” TPP (300 MVt) and “Shimal” QSTPP (400 MVt) are shown at the corrected values of options, accordingly, ACE strong action and UNITROL-5000.

The aforesaid shows, that AR PS possess superfluous capacity for export, sufficient adjusting ability and positive dynamics of some power efficiency indicators, that is important for acceptance of the positive decision on participation in UPS.

5. Azerbaijan-Georgia-Turkey "Power Bridge"

PS, entering in AGT UPS, have various structure of generating capacities (table 3). In PS of Azerbaijan and Turkey dominates (in big volume of Azerbaijan PS) power production on thermal power stations while power output on thermal power stations of Georgia PS makes about 18 %. Such distinction is important for development of schedules strategy covering UPS loadings.

Table 3. Various structure of generating capacities.

			2004	2005	2006	2007	2008	2009
INSTALLED CCAPASITY								
Azerbaijan	HPP	MVt	1.020	1.020	1.025	1.025	1.025	1.025
	Thermal	MVt	4.251	4.171	4.519	4.473	4.877	5.402
	Total	MVt	5.271	5.191	5.544	5.498	5.902	6.427
Turkey	HPP	MVt	12.645	12.906	13.063	13.395	-	-
	Thermal	MVt	24.045	25.793	27.307	27.156	-	-
	Total	MVt	36.824	38.843	40.565	40.835	-	-
Georgia	HPP	MVt	2.700	2.720	2.635	2.635	-	-
	Thermal	MVt	1.688	1.688	1.688	1.688	-	-
	Total	MVt	4.388	4.408	4.323	4.323	-	-
PRODUCTION (NETTO)								
Azerbaijan	HPP	GVt/h	2.755	3.008	2.514	2.362	2.217	2.289
	Thermal	GVt/h	18.589	19.340	21.270	19.053	18.956	16.292
	Total	GVt/h	21.344	22.348	23.7834	21.415	21.173	18.581
Turkey	HPP	GVt/h	45.623	39.165	43.802	35.492	32.950	-
	Thermal	GVt/h	98.097	114.793	123.780	145.683	154.372	-
	Total	GVt/h	143.962	154.219	167.937	181.863	188.357	-
Georgia	HPP	GVt/h	5.989	6.174	5.262	6.747	6.535	-
	Thermal	GVt/h	823	969	1.854	1.423	1.435	-
	Total	GVt/h	6.812	7.143	7.116	8.170	7.970	-

On figure 6 simplified schemes of AGT PB are shown in which II (red) are reflected. In design stages and buildings are Samuh-Gardabani, Back to back, Alhatsihi-Borchka II. Communication of Azerbaijan PS with Georgia PS is carried out on two II - 500 kV Samuh-Gardabani and 330 kV Akstafa-Gardabani II. Connection of Georgian PS with Turkey PS is carried out on back to back, established in area of Alhatsihe and OVL-400 kV Alhatsihe - Borchka. Requiring capacity for transfer in PS of Turkey is declared on a loss 650 MVt.

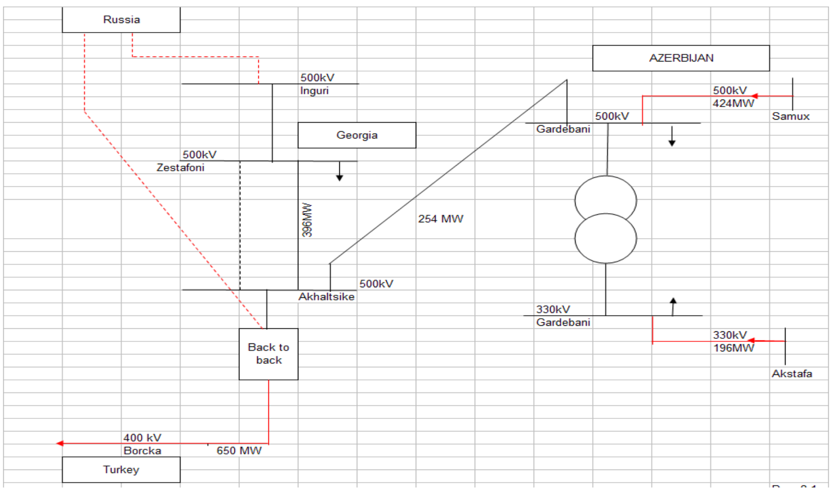

Figure 6. Scheme of capacity transmission on "Azerbaijan-Georgia-Turkey" Power Bridge.

With reference to the projected scheme (fig.6) the typical regime calculations were carried out which (winter maximum of loading) are resulted in the form of overflows on II.

The mode of a winter maximum of loading is resulted in tab. 4. The overflow of capacity from AR PS has made in the sum on two communications 600-620 MVt.

Table 4. The mode of a winter maximum of loading.

	Generation, MVt	Loading, MVt
Azerbaijan	5692	4971
Georgia	2350	2940

For a mode of capacity transfer in Georgia PS 600 MVt, including on OVL-500 kV - 322 MVt and IS-330 kV-278 MVt calculation of a mode and distribution of capacities on system connection 330-500 kV AR PS in a normal mode and in a mode n-1 is carried out. Calculations have shown that at switching-off OVL-500 kV Samuh-Gardabani the overload on current IS-330 kV Akstafa-Gardabani is possible. Thus decrease in transfer of capacity to Georgia to 475 MVt is required. Following table 4 it is seen that PA of GR is in the deficit state that can lead to frequency decrease in Georgia PS.

In other considered cases of overloads on a current and decrease in pressure in knots of AR PS is not observed.

6. Conclusions

The cited data allow saying that nowadays the Azerbaijan power system not only is ready to function in integration of Azerbaijan-Georgia-Turkey "Power Bridge", but can also be a significant component on a map of the North-South and the West-East united power grid.

Parallel synchronous work with Russia, Iran, Georgia, Turkey PS's, participation in "Power Bridge" demands working out of the regulation concept of frequency and capacity (a rule and norm) taking into account features of set up unity: deficiency of Georgia PS, small throughput of Azerbaijan - Russia II, distinction of seasonal schedules of loadings, presence of back to back on communication of Georgia and Turkey PS's, etc.

Automatics on the basis of microprocessor techniques should be considered and coordinated with reference to conditions of operating and projected emergency development of 2015. Adherence to diversification and distribution principles in generating capacities development, active introduction of renewed sources in power balance, wide-scale introduction of intellectual systems of regulation and management, measurement, the control and the account guarantees power efficiency of Azerbaijan power system and its reliability as element of integration.

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Ilham Aghasiyev - Graduated from the Energy department of Kyiv Polytechnic Institute in 1982. He is an author of more than 15 scientific publications. Sscientific research subjects: power system operational safety, efficient functioning of power grids Up to-date. How he is a Head of Central Dispatching Department in JSC "Azerenergy".

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EMERGENCY CONTROL IN ELECTRIC POWER SYSTEMS WITHIN SMART GRID CONCEPT*

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Abstract. The objective trends in electric power systems (EPSs) are discussed. New measurement, communication and control tools, information and computer technologies are considered as good possibilities for improving EPS controllability. Current emergency control system in Russia is presented. A modern approach to monitoring, forecasting and control is suggested. Some artificial intelligence applications for development of automatic emergency control in EPS are discussed.

Keywords - Electric Power System (EPS), Emergency Control, Smart Grid Concept, Intelligent Control, Intelligent Coordination.

1. Introduction

Emergency control, including emergency operation dispatching and automatic emergency control that provides reliability and survivability of the electric power grids plays an important part in controlling the operating conditions of Russia's Unified Energy System (UES). Emergency control is performed by the technological (dispatching and automatic) control systems that include the automatic systems of voltage, frequency and capacity regulation, basic automatic systems of EPS elements, relay protection and automatic line control, system emergency control [12,10].

Many thousands of emergencies and more occur usually in large power systems during a year for different reasons – short circuits, failure of equipment, errors of personnel, etc. Most of these emergencies are eliminated by relay protection devices and automatic emergency control systems. The failures of relay protection and emergency control devices and personnel errors lead to cascading development of emergencies. The automatic emergency control system of higher level localizes and eliminates such cascading emergencies. If this high level control system operates ineffectively or unreliably and additional failures and errors occur we will have unique and catastrophic blackouts like in North America and Europe in 2003 [5], Moscow blackout in 2005 [9], European blackout in 2006 [1] and others.

An important trend in electric power industry is towards integration of electric power systems and formation of regional, state and interstate interconnected electric power grids. Interconnection of EPSs results in system effects owing to maneuvering the energy resources, generation capacities and power flows.

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The integration of EPSs is primarily intended to provide consumers with power and power services of high quality on the whole territory of electric power grid. Thus the electric power industry becomes to a larger extent an infrastructural sector of the economy.

Liberalization of electric power industry leads to a principal change in the EPS organizational structure that does coincide with its technological structure and the structure of control system. The wholesale electricity market participants have principally new character of interrelations that are on the market principles. All this requires that the organization of operating and emergency control of EPS must be revised in the context of a market environment without a damage to the efficiency of the EPS operation.

As for future EPS we have to consider possible new generation and network technologies, new principles and ideas in the development and construction of electric power industry, and so on.

All these factors essentially complicate power system operation, increase its changeability and unpredictability, raise danger of severe emergencies with undesirable development and massive consequences for a system and consumers and, therefore, call for prompter and more adequate response of control systems. This generates the need to improve and develop principles and systems of power system operation control which can be based on [15]:

- new systems for measurement of operating parameters (PMU) and their control (FACTS, energy storage devices, etc.) that significantly improve EPS observability and controllability;
- modern communication systems, new information technologies and artificial intelligence methods, highly efficient computers, which totally change the processes of acquisition, transmission, presentation (visualization) and use of information on power systems;
- efficient mathematical control theory methods in multicriteria non-coincident conditions.

Based on the above circumstances the so called Smart Grid concept was developed [4, 3].

Smart Grid concept relates to energy generation, transmission, distribution and delivery. This concept means the use of:

- Highly intelligent systems for monitoring and control, integration and control of renewable sources, distributed generation and energy storage devices on the basis of the Internet technologies;
- Wide area monitoring of operating conditions and their control with the help of new devices and technologies (FACTS, PMU, artificial intelligence, etc.);
- Distributed microprocessor-based control and protection systems, new information and computer technologies;
- Highly intelligent systems intended for electricity control and metering for consumers, demand-side management and load control in emergency situations.

Emergency control ideology in UES of Russia is a hierarchical approach and is realized by coordinated operation of many control devices, which maintain EPS stability and interrupt the expansion of emergency situation in the case of stability violation and a treat of undesirable cascade emergency development. Coordinated emergency control is realized by joint participation of generators, network and consumers.

The paper deals with the analysis of current emergency control system of UES of Russia and possible ways to develop Smart Grid concept concerning advanced emergency control system by using new technologies and devices.

2. Emergency control system in russia

The electric power object called "Unified Energy System of Russia" is a power interconnection, where seven Interconnected Power Systems (IPSs) are combined by weak ties. Under the emergency conditions the UES of Russia as a power interconnection is able to disintegrate into autonomously operating self-balanced IPSs without grave consequences. At the same time disintegration of any of the mentioned seven IPSs is far from smooth. Because of large power flows in the ties, practically any disintegration creates parts with power lack and power surplus. As a result, load and generator disconnections are quite possible and can acquire a cascade character, i.e. turn into system crash fault. For this reason at the IPS level the generator and load disconnections by special system emergency devices (in order to unload cutsets and to maintain admissible values of operation parameters) are of course more preferable than cascade disconnection by protection devices (after these parameters go beyond the fixed limits). Just this principle is basic for arranging the emergency control in Russian EPSs [12,10,5,6].

The emergency control system in Russia's IPSs includes the following components:
A) Dispatching emergency control: to provide admissible loading of the electric network ties according to the Guidelines on power system stability [7].
B) Automatic emergency control:

▷ *In pre-emergency conditions* - to maintain necessary transfer capabilities of ties by efficiently controlling them through the use of PSS; control systems of reactive power sources, DC links, etc.

▷ *In emergency conditions* -

- The above automatic controllers and control systems – to maintain the voltage levels and damp the oscillations in EPS;
- Automatic stability control of EPS;
- Automatic frequency load shedding; automatic voltage deviation limiting, automatic isolation of power plants with maintaining the auxiliary power supply, etc.

C) Restoration of EPS after large emergencies.

The main principles of emergency control system operation in Russia's IPS are:

– Observation of standard transfer capabilities margins in electric ties in pre-emergency and post-emergency operating conditions;
– Echelonized system of automatic emergency control whose actions are coordinated in order, depending on type, time and severity of emergency; the system is aimed at interrupting the emergency process development at its earliest stage;
– Prevention of development and interruption of severe system emergency is an exclusive prerogative of the automatic emergency control system due to a fast development of the process and, therefore, impossibility for dispatcher to act adequately; after a large emergency EPS is mainly restored by dispatching personnel through the use of some automatic systems.

It is important to draw the attention on hierarchical two level automatic centralized emergency control system which realizes effective stability control of EPS. This system collect and process information regarding current state and disturbances in a large EPS region or in the entire power system. The remedial actions are supported by analytical tools and may include a variety of geographically dispersed measures triggered by sophisticated algorithms. The algorithms perform the following functions:

- identifying the danger of instability and decision making whether remedial control actions are necessary;

- selecting the most effective control actions to prevent instability from the arsenal of available remedial actions;
- determining the size of the corrective remedial control actions.

Above mentioned main principles and components of emergency control system of Russia's UES show that this control system has just now the elements of Smart Grid ideology. Such elements include:

▷ *adaptability by* coordination of control actions in order, depending on type, time and severity of emergency; echelonized control system is tried to interrupt the cascading emergency process the sooner the better;

▷ *optimality* in the control actions especially by hierarchical two level automatic centralized emergency control system which includes the top coordinating subsystem with fast algorithms for optimal choosing of control actions for control devices on the bottom level;

▷ *intellectuality* of decision making process with the learning and optimal control actions in the hierarchical two level automatic centralized emergency control system; such a system has the properties of multi-agent systems.

3. The system of monitoring, forecasting and control of EPS

Advanced smart devices and technologies, such as PMU, artificial intelligence and so on give new possibilities for solving complex and comprehensive problem of emergency control using monitoring, forecasting and control of EPS operating conditions. Time sequence of individual stages of monitoring, forecasting and control of operating conditions is shown in Fig. 1.

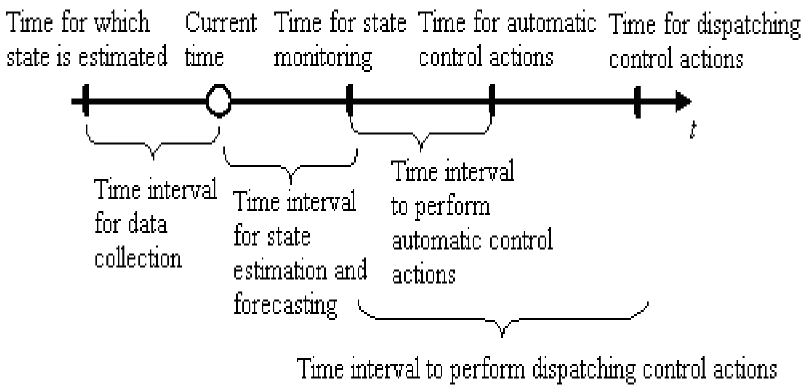

Figure 1. Time diagram of events in the system for monitoring, forecasting and control in EPS.

In essence this combination of stages represents a comprehensive system providing stability, reliability and controllability of modern power systems. At the same time from the viewpoint of efficiency of this system it is essential to increase the adaptability of control and improve coordination of the control stages, means and systems. The blocks of monitoring and forecasting of the EPS normal, pre-emergency and post-emergency operating conditions include the following problems:

- System state estimation.
- Forecasting the parameters of expected operating conditions. Forecasting is necessary because during the state estimation procedure current state is estimated with some delay, while monitoring and control problems require some advance estimation of system state

("to control is to foresee"); let us note that for these two blocks of problems the advance time can vary.
- Detection of weak points in the system in the expected operating conditions.
- Determination of margins for transfer capabilities of ties in the expected conditions; this is necessary for efficient use of the margins in operating conditions and for automatic control through appropriate control actions.
- Visualization of expected conditions. Determination of indices and criteria for transition from normal to pre-emergency conditions and, vice versa, from post-emergency to normal conditions.
- Effective organization of the system of EPS operating condition monitoring and control is possible by an extensive involvement of new tools for the analysis and calculations of operating conditions and control actions, primarily technologies of artificial intelligence.

4. Artificial intelligence application

Let us consider some specific possibilities of artificial intelligence application to development of principles and tools of automatic emergency control in EPS.

A. Adaptation of a fuzzy logic-based AVR of generators

A fuzzy regulator is automatically adapted over the whole region of values of operating conditions, variants of networks (normal, maintenance, post-emergency) and studied disturbances at the set time interval (day, week, month, etc.). The problem is solved at two stages [14].

At the first stage the fuzzy regulator parameters are tuned off-line for the finite set of studied situations – combinations of network variants, operating conditions and studied disturbances. The fuzzy regulator parameters are optimized for each studied situation by using the genetic algorithm. The initial set of studied situations and the obtained optimal parameters of the fuzzy regulator are a learning sample for the artificial neural network learning.

At the second stage the learned artificial neural network chooses on-line tuning parameters of the fuzzy regulator that are optimal for the current situation.

Figure 2 illustrates efficiency of damping generator rotor oscillations for the test EPS by the suggested adaptive fuzzy regulator at system disturbance.

It is important to note, that in this and following subsections rather extreme emergency scenarios were used to better demonstrate the efficiency of the suggested techniques.

B. Coordinated emergency control of load and FACTS devices

Special automatic load shedding systems (SALS) are an effective means of emergency control to interrupt cascading emergency processes and prevent EPS instability. However, nowadays the earlier applied forced principles of SALS arrangement do not suit consumers more and more, since they contradict the ideology of market relations. Hence, the question arises, whether it is possible to transfer, though partially, the SALS functions to other feasible devices, for example FACTS [12].

The method has been devised for coordination of emergency control of loads and FACTS devices, when it is needed to unload transmission lines to prevent emergency development. Application of FACTS devices on the unloaded lines enhances efficiency of using these lines and hence, decreases the volume of load tripped because of emergency situations. This fact makes it possible to minimize the total damage due to load shedding in emergency situations, preserving efficiency of emergency control of EPS as a whole.

Figure 3 illustrates efficiency of the suggested coordinated emergency control at emergency disconnection of one transmission line in the test EPS.

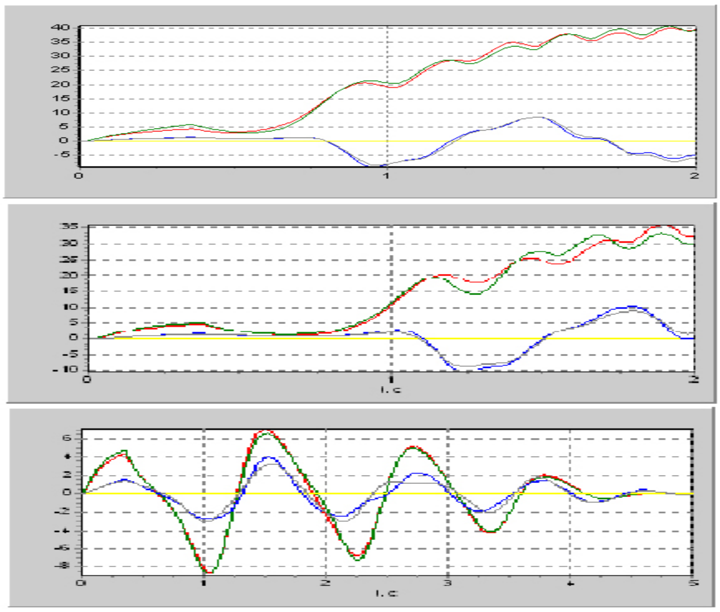

Figure 2. Variations of the angular velocity of generator rotors at emergency disconnection of line: *a*-for traditional AVR; *b*-for fuzzy AVR with expert tuning; *c*-for fuzzy AVR with optimal tuning.

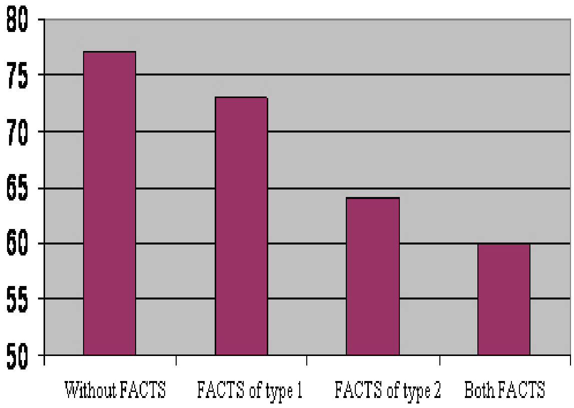

Figure 3. Efficiency of coordinated emergency control of load and FACTS devices.

C. Dynamic control of FACTS using PMU

As a rule the automatic control systems of EPS, in particular automatic regulators installed at FACTS devices, use local information on the system state. This measure is not always effective for prevention of emergency situations especially at intersystem oscillations to occur in bulk extended EPSs [2].

The studies have been performed on the possible use of signals received from WAMS on the basis of PMU measurements as initial information for FACTS regulators. The static thyristor-controlled series compensator is considered as a FACTS device.

Stage 1 of studies deals with the application of local signals to control static thyristor-controlled series compensators. Their regulators were optimized for maximum damping of rotor oscillations during disturbances. The results show that joint application of the static thyristor-controlled series compensators and PSSs prevents from EPS instability in such considered situations, when the system stability is lost without these compensators with optimized tuning.

However, during heavy disturbances the static compensator control based on local operating parameters may happen not to cope with its function and the EPS stability can be lost. Figure 4,*a* presents a similar situation for the test EPS. The use of information from WAMS allows the successful solution to the problem of system stability conservation (Figure 4,*b*). Adaptation of tuning of static compensator control system that is similar to the described one for the fuzzy voltage regulator enhances control efficiency all the more.

D. Development of out-of-step protection using PMU

Out-of-step operation in EPS is the one the most severe emergencies. It is related to the loss of stability in EPS which may cause damage to equipment, interruption of power supply to consumers and unwanted development of emergency processes with severe consequences for EPS and consumers. Special automatic out-of-step protection systems (OSPS) have been used in EPS for reliable, timely and selective detection and elimination of out-of-step conditions [10].

Further development of selective OSPS has resulted in creation a multifunctional device. The device makes it possible not only to eliminate the out-of-step conditions if they have occurred but also to prevent their occurrence. It has two stage of control actions: the control actions of the first stage are intended to prevent the loss of stability and for this purpose generation is disconnected in the surplus part of the system and fast reserve is used (or secondary load is shed) in the deficient part. If these control actions are insufficient and fail to prevent out-of-step operation the control actions of the second stage are triggered and split EPS.

The use of synchronized voltage phase measurements obtained from PMU offers principally new capabilities of implementing the selective the selective out-of-step prevention and protection system (SOSPPS) [11].

Loss of synchronism in EPS operation in some cutest can be caused by two main reasons:

- the maximum admissible transfer capability of the cutest is exceeded and, thus, the aperiodic small signal stability of the system is lost;
- the transient stability is lost as a result of disturbance in one of the ties or near the considered cutest.

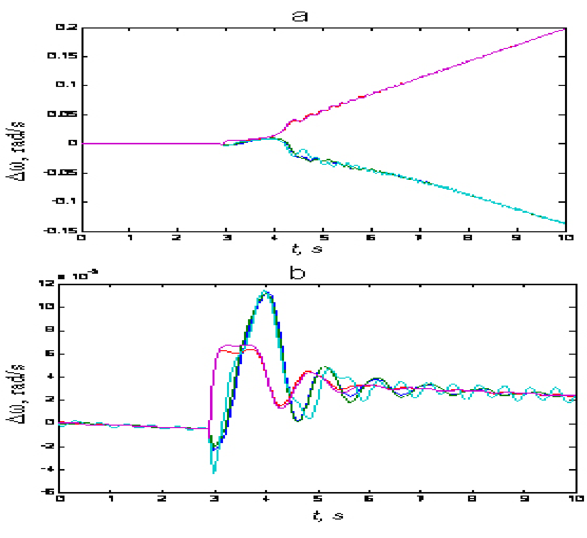

Figure 4. Deviation of the angular velocity of generator rotors during disturbances.

Figure 5 shows the interrelations between EPS states and control actions in SOSPPS. The secure state of EPS is determined by the condition $|\delta_{ij}|$. PMU measurements are used to trace the current value of $\delta_{ij}\,(t) = \delta_i\,(t)$, where and are voltage phases on the ends of the most critical tie of the considered cutest. The dangerous state of EPS occurs at $|\delta_{ij}|$, emergency state occurs at $|\delta_{ij}|$, where $|\delta_{ij}|$. Difference between and considers the margin of transfer capability of cutest.

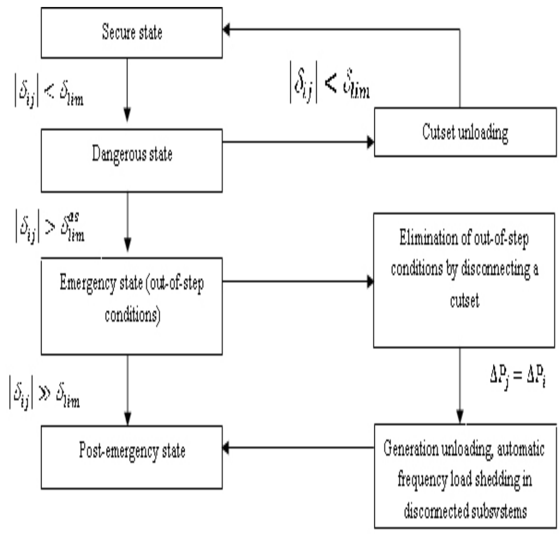

Figure 5. A scheme of interrelation between power system states and control actions in SOSPPS.

E. Multi-agent coordination of emergency control devices

Analysis of the recent blackouts shows, that the most severe contingencies which lead to voltage collapse occur in highly loaded EPS without effective coordination of emergency control devices operation.

The proposed in [8] multi-agent control system provides reactive power control by coordinating the operation of different discrete and continuous control devices in a post-disturbance period in order to prevent voltage collapse of the whole EPS. The model of the test system was simulated by Matlab/PSAT software. Multi-agent control system (MACS) has been implemented in JAVA language using JADE package. The efficiency of proposed technique has been proved by numerical simulations. The proposed MACS allows the use of complex Matlab/PSAT routines as well as the modeling of complex behavior of the agents.

To test the proposed MACS the following sequence of disturbances is examined for test EPS:

- 2 seconds after the simulation start – loss of one generator;
- 40 seconds after the simulation start – loss of one line.

Conventional control system includes Automatic Voltage Regulators (AVR) and Over Excitation Limiters (OXL) for generators, Under Voltage Load Shedding (UVLS) for loads, Under Load Tap Changes (ULTC) of transformers, which operate without coordination. Proposed MACS coordinates the operation of these devices. Figures 6 and 7 show the voltage transients in test EPS without and with MACS, respectively.

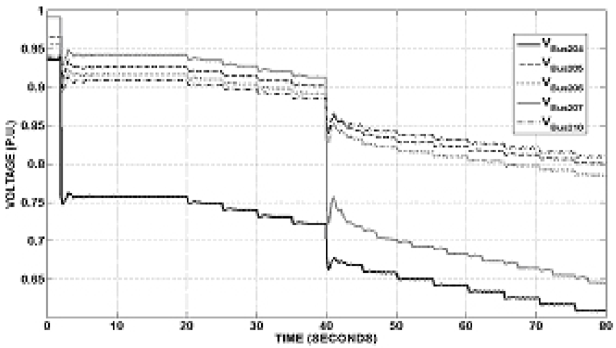

Figure 6. Changes in HV substation voltage level without coordination.

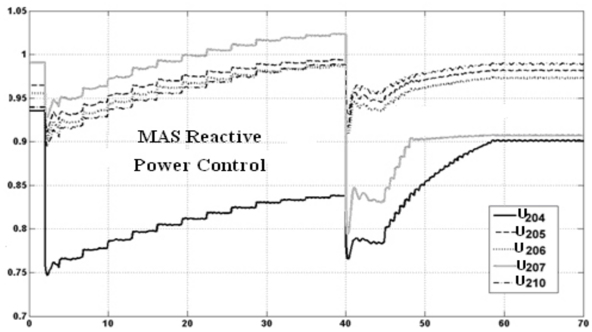

Figure 7. Changes in HV substation voltage level with coordination.

5. Conclusions

Integration of EPSs, liberalization and modernization of electric power industry increase changeability and unpredictability of EPS operation and generate the need to improve and develop principles and systems of operation and emergency control. Current emergency control system in Russia is rather developed and already now has the elements of Smart Grid ideology. New conditions call for development of a comprehensive system for monitoring, forecasting and control of EPS. Artificial intelligence application is an advanced way to carry out smart emergency control in EPS.

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This direction was recognized by Russian Fund of Basic Researches in 1996 as a leading scientific school of Russia, with award of the special grant of support. It was published more than 180 scientific works, including 14 monographers by him. Most important of them are Simplification of mathematical models of dynamics of power systems", "Management with powerful power integrations" and "The structural analysis of power systems".

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DEVELOPMENT OF WORLD WIND-POWER ENGINEERING AND PRELIMINARY FEASIBILITY STUDY OF 50 MW WIND POWER FARM IN AZERBAIJAN

R.I.MUSTAFAYEV [1], L.H. HASANOVA [2]

Abstract. The survey of world wind-power engineering development in producing electric power countries on a basis of wind power conversion, and also the rating table of manufacturing wind power plants countries and relevant firms is carried out. Along with this the bases of wind power farm construction feasibility study in Azerbaijan are given – locality performance, research of a wind power potential, expected output estimation and selection of wind power plants optimum types for the given locality and wind characteristics.

Keywords: Wind-power Engineering, Wind Speed, Electric Power Production, Wind Power Plants (WPP).

1. Introduction

Now a wind power among renewable power sources takes according to its significance the third place in a planet for electric power output (3,5% of total electric power generation from renewable power sources). It is much less, than the water-power engineering share (89%) and some less, than electric power production from biomass (5,7%). But unlike these two directions a growth of electric power generation from wind power has considerable more dynamics.

Basing on accelerated development and the further policy improvement in wind-power field development WWEA (World Wind Power Association) considers that by 2020 reaching of world wind-power engineering the level of 1900000 MW of an installed capacity will become real. The total installed capacity of world wind-power engineering by the end of 2010 will exceed 200000 MW (fig.1).

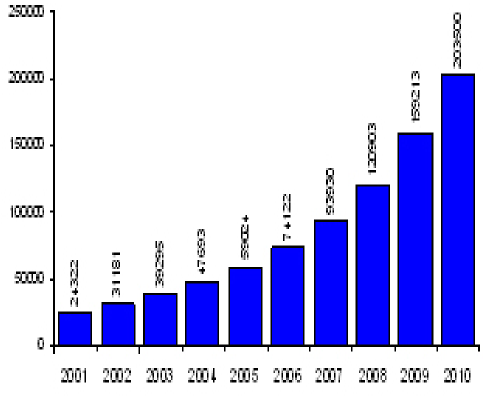

Figure 1.World total installed capacity.

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The annual electric power production by the all installed in the world by the end of 2009 wind power plants constituted 340 TWh, that corresponds to total electric power consumption of Italy – the country, which according to its economic development takes the seventh place in the world and estimates 2% of a world electric power consumption. The installed capacity of world wind power branch by the end of 2009 reached 159213 W from which 38312 W have been input into operation in 2009. The rate of wind-power engineering growth in 2009 constituted 31,7 %.

In some countries and regions of the world a wind has become one of the demanded power sources, particularly the wind power share of power supply constitutes:

- in Denmark: 20%
- in Portugal: 15%
- in Spain: 14%
- in Germany: 9%

In 2009 the world wind–power engineering developed in 82 countries on a commercial basis, 49 countries of which have increased their installed wind power capacity.

China and USA have proved to be the greatest markets for raising wind power capacities, 61,9% of all inputted new capacities fell on their share, which has considerably exceeded a previous year index (53,7%).

Nine countries are considered as the basic world markets with wind turbines sale volume at a rate of from 0,5 to 2,5 GW, namely: Spain, Germany, India, France, United Kingdom, Canada, Portugal and Sweden (fig.2).

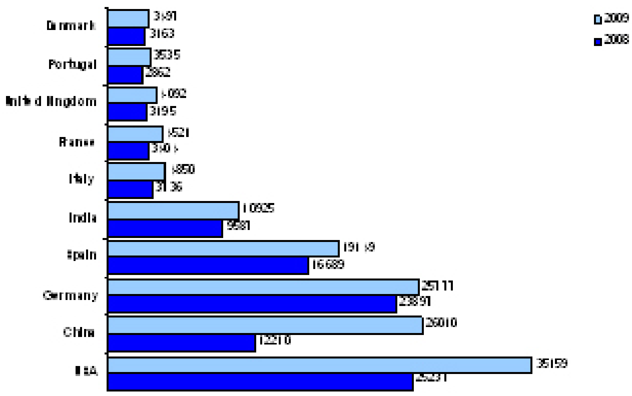

Figure 2. Top 10 countries total capacities.

In the markets of twelve countries – Turkey, Australia, Denmark, Mexico, Brazil, Ireland, Poland, Japan, New Zealand, Belgium, South Korea and Greece the sales volumes of new wind turbines have constituted from 100 to 500 MW.

On a share of USA and China falls together 38,4% of installed in the world wind power capacities. Five countries – leaders (USA, China, Germany, Spain and India) represent 72,9% of world wind power engineering, which is not much above of 2008 index – 72,4%.

The countries–regions and their places in a rating of 2009 are presented in table 1.

Today a real boom of input into operation the wind power plants (WPP) of from 1 to 5 MW unit capacity is observed.

For all this rather more than 30 companies all over the world are engaged in manufacture of such WPPs, of which the large producers are about ten ones.

Occurrence of the strongest power–machine-building concerns, experienced the enormous prospects of the renewable power engineering became recently the characteristic feature of this market. So, Siemens the well-known German company has bought the Danish producer of WPP Bonus and German producer of AN Wind, Areva the French concern has bought Multibrid the German company, and Alstom the French giant has purchased Spanish producer of Ecotecnia. For a long time such concerns, as American General Electric and Japanese Mitsubishi Heavy

Industries are presented in the given market. Hyundai Heavy Industries the South Korean company matures the serious plans, they master this manufacture, as the saying goes, "from scratch". Perhaps presently only ABB concern is not directly engaged in WPPs manufacture, though it actively participates in the development and adoption of solutions on wind plants connection to electric power networks.

Let's observe in detail, whish companies are today the leaders in powerful wind power farms manufacture.

The world leader for a long time is Vestas the Danish concern, in practice every fourth power megawatt of run in world WPPs is generated by the power plants of this producer. Today this concern, created more than 20 years ago, and absorbed within this time such companies as NegMicon, Nordtank, Windane, Wind World and NedWind, produces the serial plants of from 0,85 to 3 MW unit capacity. As of 30th of June 2009 the total WPPs' capacity of this concern all over the world has exceeded 35000 MW, 7061 MW of which have been input into operation in Germany, 6618 MW in USA, 2808 MW in Spain, 2434 MW in Denmark, 2141 MW in India.

Vestas has branches in all continents, its working areas are situated in many countries.

The second place according to total WPPs' installed capacity is occupied with Enercon the German firm, its factories, besides the Germany, are in Portugal, Sweden, Turkey, India and Brazil. Furthermore Enercon has representations in 15 countries. The total capacity of operating today in the world WPPs of this producer as of the beginning of November 2009 has reached 19000 MW. The range of plants capacities is equal to from 0,33 to 2,3 MW. The serial production of WPPs of 6 MW capacity is in the making.

The third place is so far kept by one else large producer, who is based in Europe, – Gamesa the Spanish concern. Not so long ago it has absorbed one more Spanish company – Made. A manufacturing line of these enterprises includes the WPPs of from 0,8 to 3 MW capacity. Being the unconditional leader of the Spanish market, the company has the subdivisions in other European countries, and also in the North America and Asia. The total capacity of Gamesa WPPs constitutes already about 16000 MW.

Table 1.

Rating seat the course of 2009	Countries/ regions	Total installed capacity, the turn the course of 2009 [MW]	New power the course of 2009 [MW]	Growth rate 2009 [%]	Place for 2008	Total installed capacity, the turn of 2008 [MW]	Total installed capacity, the turn of 2007 [MW]	Total installed capacity, the turn of 2006 [MW]
1.	USA	35 159,0	9 922,0	39,3	1	25 237,0	16 823,0	11 575,0
2.	China	26 010,0	13 800,0	113,0	4	12 210,0	5 912,0	2 599,0
3.	Germany	25 777,0	1 880,0	7,9	2	23 897,0	22 247,4	20 622,0
4.	Spain	19 149,0	2 460,0	14,7	3	16 689,0	15 145,1	11 630,0
5.	India	10 925,0	1 338,0	14,0	5	9 587,0	7 850,0	6 270,0
6.	Italy	4 850,0	1 114,0	29,8	6	3 736,0	2,726,1	2,123,4
7.	France	4 521,0	1 117,0	32,8	7	3 404,0	2 455,0	1 567,0
8.	United Kingdom	4 092,0	897,0	28,1	8	3 195,0	2 389,0	1 962,0
9.	Portugal	3 535,0	673,0	23,5	10	2 862,0	2 130,0	1 716,0
10.	Denmark	3 497,0	334,0	10,6	9	3 163,0	3 125,0	3 136,0
11.	Canada	3 319,0	950,0	40,1	11	2 369,0	1 846,0	1 460,0
12.	Netherlands	2 240,0	5,0	0,2	12	2 235,0	1 747,0	1 559,0
13.	Japan	2 056,0	176,0	9,4	13	1 880,0	1 528,0	1 309,0
14.	Australia	1 877,0	383,0	25,6	14	1 494,0	817,3	817,3
15.	Sweden	1 579,0	512,0	48,0	16	1 066,9	831,0	571,2
16.	Ireland	1 260,0	233,0	22,7	15	1 027,0	805,0	746,0
17.	Greece	1 109,0	119,0	12,0	18	989,7	873,3	757,6
18.	Austria	995,0	0	0	17	994,9	981,5	964,5

19.	Turkey	796,5	463,1	138,9	25	333,4	206,8	64,6
20.	Poland	666,0	194,0	41,1	19	472,0	276,0	153,0
21.	Brazil	600,0	261,5	77,3	24	338,5	247,1	236,9
22.	Belgium	555,0	171,0	44,6	22	383,6	286,9	194,3
23.	New Zealand	497,0	172,0	52,9	26	325,3	321,8	171,0
24.	China Taipei	436,0	78,0	21,8	23	358,2	279,9	187,7
25.	Norway	431,0	2,0	0,5	20	429,0	333,0	325,0
26.	Egypt	430,0	40,0	10,3	21	390,0	310,0	230,0
27.	Mexico	402,0	317,0	372,9	34	85,0	85,0	84,0
28.	South Korea	364,4	86,4	31,1	27	278,0	192,1	176,3
29.	Morocco	253,0	129,0	104,0	32	124,0	125,2	64,0
30.	Bulgaria	214,2	56,7	36,0	28	157,5	56,9	36,0
31.	Hungary	201,0	74,0	58,3	31	127,0	65,0	60,9
32.	Czech Republic	191,0	41,0	27,3	29	150,0	116,0	56,5
33.	Finland	147,0	4,0	2,8	30	143,0	110,0	86,0
34.	Estonia	142,3	64,0	81,8	36	78,3	58,6	33,0
35.	Costa Rica	123,0	49,5	66,9	37	74,0	74,0	74,0
36.	Lithuania	91,0	37,0	68,0	38	54,4	52,3	55,0
37.	Ukraine	90,0	0	0	33	90,0	89,0	85,6
38.	Iran	82,0	0	0	35	82,0	66,5	47,4
39.	Chile	78,0	58,0	288,6	47	20,1	20,1	2,0
40.	Nicaragua	40,0	40,0	new	new	0	0	0
41.	Luxemburg	35,3	0	0	39	35,3	35,3	35,3
42.	Philippines	33,0	8,0	31,8	42	25,2	25,2	25,2
43.	Argentina	29,8	0	0	41	29,8	29,8	27,8
44.	Jamaica	29,7	9,0	43,5	44	20,7	20,7	20,7
45.	Latvia	28,5	1,6	5,9	40	26,9	26,9	26,9
46.	Croatia	27,8	9,6	52,9	50	18,2	17,2	17,2
47.	Netherlandian Antilles	24,3	12,0	97,6	54	12,3	12,3	12,0
48.	SAR	21,8	0	0	43	21,8	16,6	16,6
49.	Guadeloupe	20,5	0	0	45	20,5	20,5	20,5
50.	Uruguay	20,5	0	0	46	20,5	0,6	0,2
51.	Colombia	20,0	0	0	49	19,5	19,5	19,5
52.	Tunisia	20,0	0	0	48	20,0	20,0	20,0
53.	Switzerland	17,6	4,0	29,0	52	13,8	11,6	11,6
54.	Russia	16,5	0	0	51	16,5	16,5	15,5
55.	Rumania	14,0	7,0	100,0	56	7,0	7,8	2,8
56.	Guyana	13,5	0	0	53	13,5	13,5	13,5
57.	Vietnam	8,8	7,5	600,0	66	1,3	0	0
58.	Cuba	7,2	0	0	55	7,2	2,1	0,5
59.	Israel	6,0	0	0	57	6,0	6,0	6,0
60.	Slovakia	6,0	0	0	58	6,0	5,0	5,0
61.	Pakistan	6,0	0	0	58	6,0	0	0
62.	Faeroe Islands	4,1	0	0	60	4,1	4,1	4,1
63.	Cape Verde	2,8	0	0	62	2,8	2,8	2,8
64.	Ecuador	2,5	0	0	61	4,0	3,1	0
65.	Mongolia	2,4	0	0	63	2,4	0	0
66.	Nigeria	2,2	0	0	64	2,2	2,2	2,2
67.	Belarus	1,9	0,9	77,3	68	1,1	1,1	1,1
68.	Antarctica	1,6	1,0	165,0	73	0,6	0	0
69.	Jordan	1,5	0	0	65	1,5	1,5	1,5
70.	Indonesia	1,4	0,2	16,7	67,0	1,2	1,0	0,8
71.	Martinique	1,1	0	0	68	1,1	1,1	1,1

72.	Falkland Islands	1,0	0	0	70	1,0	1,0	1,0
73.	Eritrea	0,8	0	0	71	0,8	0,8	0,8
74.	Peru	0,7	0	0	72	0,7	0,7	0,7
75.	Kazakhstan	0,5	0	0	74	0,5	0,5	0,5
76.	Namibia	0,5	0	0	74	0,5	0,5	0,3
77.	Syria	0,5	0,1	22,5	76	0,4	0,3	0,3
78.	Dominican Republic	0,2	0	0	77	0,2	0	0
79.	Dominica	0,2	0	0	77	0,2	0	0
80.	North Korea	0,2	0	0	77	0,2	0	0
81.	Algeria	0,1	0	0	80	0,1	0	0
82.	Bolivia	0,01	0	0	81	0,01	0,01	0,01
	TOTAL	159 213,3	38 312,0	31,7		12 902,9	93 930,4	74 122,8

The fourth WPPs producer is the above mentioned concern General Electric (GE), installed for today about 15000 MW. Such producers, as Enron, Zond and Tacke have previously joined this giant. In 2009 GE has purchased ScanWind the young Norwegian producer. GE operating capacities besides the USA are in Canada, Germany, Spain and China.

GE makes WPPs of 1,5; 2,5 and 3,6 MW capacity and also is one of the leaders on plants manufacture for so-called offshore wind farms, built in coastal zones (50 kilometers beyond a shore as a rule).

One more major participant of the market is Siemens the international concern, which has been engaged in WPPs making after purchasing of such producers, as Bonus and AN Wind.

Siemens along with Vestas and GE is one of the leaders in an offshore segment.

For today the total capacity of this producer's plants constitutes about 8500 MW, and a production line consists of WPPs of 2,3 and 3,6 MW capacity.

Acciona the Spanish company according to 30th of September 2009 data has input into operation the WPPs of more than 7500 MW total capacity, about 5850 MW of them (78 percents) operate in Spain itself. Plants of this producer are exploited in 14 countries else, and now the wind farms are under construction in other 5 countries. Acciona produces WPPs of 1,5 and 3 MW capacity.

The major Asian producer is Suzlon the Indian company, created in 1995 by known Indian businessman Tulsi Tanti. Suzlon has working areas and research centers in India, China, Denmark, Netherlands, Belgium, Germany and USA. The company is presented in all regions.

Today Suzlon's total WPPs capacity exceeds 6000 MW, the production line includes the models of from 0,6 to 2,1 MW.

It is necessary to note also that not so long ago Suzlon has bought the majority of actions of created in 2001 German producer of Repower. The last one has already installed WPPs of about 3500 MW. Repower is by right considered as one of the technical progress leaders in observed branch. This company first-ever in the world has started a series production of 5M plant of 5 MW capacity, and now masters a production of 6M new series of 6,15 MW capacity. For all this Rpower makes stations both for land, and for coastal wind farms.

One more German producer – Nordex company deserves to be mentioned. Established in 1985 in Denmark, this firm is based today in Germany and has an industrial branch in China. For today almost 5500 MW WPPs of Nordex brand are installed in the world.

Mitsubishi Heavy Industries (MHI) the Japanese giant started the investigations in wind-power engineering field in the beginning of 80th of past century, and produced a first WPP of 1 MW capacity in 1996. Today the company makes the plants of 1 and 2,4 MW capacity and actively masters the North American market.

To complete it is necessary to mention the Chinese producers, who can change essentially in the nearest future the developed for today state of affairs owing to rapid growth of their native market.

Today in China some tens companies in total are engaged in WPPs production, the largest of them (without taking into account the industrial branches of already mentioned companies Vestas, Suzlon, GE, Gamesa, Nordex and Repower) are Xinjiang GoldWind, Sinovel Windtech and Dongfang Steam Turbine.

The interesting fact is the part of the considered producers (Suzlon, Gamesa, Acciona) not only makes and sells WPPs, but also is independently engaged in building and maintenance of large wind farms in various world regions. The share of producers of WPPs with respect to their total world capacity is presented in fig 3.

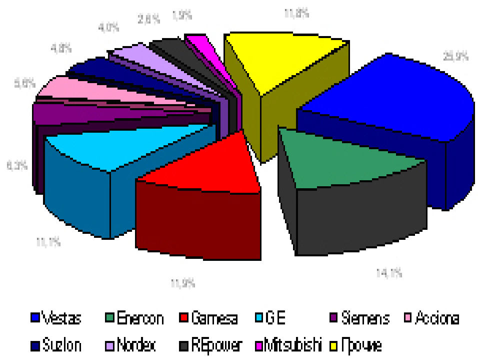

Figure 3. The share of producers of WPPs on company

A list of firms, produced the WPPs, with a scale of WPPs' rated powers is presented in table2.

The researches in wind power field were begun in Azerbaijan in 60th years of last century [1]. At that time firstly in the Soviet Union a wind power cadastre has been made in Azerbaijan: i.e. the isodynamic map of republic have been presented, have been determined the yearly average

Table 2.

	Company	**Country**	**Rated capacities produced WPPs, kW**
1.	Vestas	Denmark	850, 1650, 1800, 2000, 3000
2.	Enercon	Germany	330, 800, 900, 2000,2300
3.	Nordex	Germany	2300, 2500
4.	Siemens	Germany	2300, 3600
5.	REpower	Germany	2050, 3300, 5000, 6150
6.	Fuhrlaender	Germany	30, 100, 250, 600, 1250, 1500, 2500
7.	Dewind	Germany	1250, 2000
8.	Multibrid	Germany	5000
9.	Vensys	Germany	1200, 1500
10.	Bard Engineering	Germany	5000
11.	Innovative Windpower	Germany	1250
12.	Gamesa	Spain	850; 2000
13.	Ecotecnia	Spain	1670; 2000; 3000
14.	Made	Spain	800;1320
15.	Acciona	Spain	1500; 3000
16.	Mtorres	Spain	1650

17.	WinWinD	Finland	1000; 3000
18.	Vergnet	France	275; 1000
19.	Nordic	Sweden	1000
20.	Global WindPower	Netherlands	750; 2000
21.	Harakosan	Netherlands	2000
22.	ScanWind	Norway	3500
23.	Leitwind	Italy	1500; 1700
24.	CKD Nove Energo	Czech Republic	1200
25.	GE	USA	1500; 2500; 3600
26.	Clipper	US	2500
27.	Suzlon	India	600; 1250; 1500; 2100
28.	Mitsubishi	Japan	1000; 2400
29.	Hyundai Heavy Industries	South Korea	1650; 2000; 2500
30.	Hyosung	South Korea	750; 2000
31.	Xinjiang Gold Wind	China	600; 750; 1200; 1500
32.	Dongfang Steam Turbine	China	1500
33.	Sinovel Windtech	China	1500; 3000

wind speeds, recurrence regimes and so forth (fig. 4). In those years 58 state weather stations (SWS) of 90 ones have been selected, and processing have been made on them.

Then it was already revealed, that Apsheron with adjoining islands and coastal Caspian zone were from the wind power point of view the region with high wind power potential, where yearly average wind speeds at SWS level (10–12m) were within a range of 5,5–7,5 m/s. The works have been carried out in Energetics Institute.

Further in 80th of last century also for the first time in the Union the Energetics Institute has organized a continuous wind speeds record at different heights of 20; 50; 80; 120 m with using the wind power sensors, were in a set of meteorological stations M-49, which leads through matching devices have been connected to self-recording instruments H-352. The equipment has been placed in a TV tower (old) of Baku. A processed data has allowed to determine a dependence of yearly average wind speeds on a height: for Apsheron this factor is within the limits of 0,15–0,25 (0,2 on the average). Also it has been revealed that for this region yearly average speed at the above 150–200 m heights a yearly average speed varied insignificantly. The conclusion has been drawn, that when designing high-altitude WPPs, it is necessary to be based not only on integral wind power performances of region, highlighted an economical part of a problem, but also to take into consideration the wind dynamic characteristics, defining the engineering aspects of WPPs functioning [2,3].

And, at last in the end of last century–beginning of this one, the Institute jointly with "Tomen" the Japanese consulting firm installed in Gobustan region two towers of 40 m height with two anemometers, placed at a heights of 40 and 30 m. Wind speed and its direction have been recorded on CHIPs with 10 minutes averaging and processed on personal computer [2].

All these researches have allowed determining the total potential of electric power output by means of wind power in Absheron region of republic.

It means that for a long-term prospect in wind zones of republic (where $Vav \geq 5,5m/s$ at SWS level) and with taking into account only 40% of the lands, suitable for WPPs installation, 1000 WPPs of 3 MW unit capacity can be installed for operation with rated power equal to 3000–3500 hours. If to define the suitable lands for WPPs installation as equal to 20% (it is easy attainable outcome), a wind power potential will naturally estimate about 5-6 billion kWh (i.e. WPPs' installed capacity will be at a level of 1500-2000 MW). These indexes doesn't allow for WPPs installation in so-called offshore zone of Caspian Sea (i.e. directly in a sea shelf near a shore).

Data of preliminary feasibility study of wind power farm construction in Azerbaijan is given below.

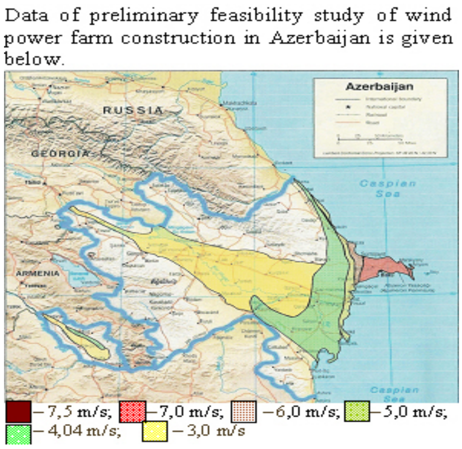

Figure 4. The isodynamic map of republic

In the investigated Gobustan region a wind power farm of 100 MW total capacity is supposed to be installed. The first stage, which preliminary validation is given below, constitutes 50 MW.

Design data on Absheron's Gobustan region wind performances are specified, well-grounded selection of the best types of the newest foreign WPPs and also the data according to their rated power when operating in defined installation area are substantiated. Detailed performance specifications of chosen WPPs are substantiated, a description of their design features is given. Designing and placing problems of wind power complex and also a connection of observed, chosen wind power complex to existing electric power network are considered.

The prospective site of WPPs complex installation (WPF) is Gobustan region, it is situated approximately at 30 km distance to north-west from Baku, to the south from Baku-Shemakha basic route, a pilot power of WPF constitutes 50 MW (first stage) (fig. 5).

A lay of land varies in the limits of from 150 to 340 m above sea level. The area is hilly one. There is no vegetation in the site and land is very plain. Hereabout there are no orographical installations, no human settlements or separate buildings.

Figure 5. Characteristic area for building WPPs in Azerbaijan.

The disposition near to asphalt route promotes unobstructed transportation of the equipment from Baku or Sumgait to WPPs installation site.

Ground is firm and stony one, so a quality of the road, departing from the basic route to object, seems rather acceptable for WPPs transportation. A soil around a site is stable enough

and capable to stand a heavy machinery travel. The amount of precipitation, able to wash-out a soil in this region, occurs to a little degree.
A first estimation of wind characteristics have been carried out on a database of wind speeds of Sumgayit, Mashtaga and Artem island (Pirallakha) weather stations (fig. 6).

All three stations are characteristic that all of them are far from the future WPF (Sumgayit – 20 km, Mashtaga – 45 km, Artem – 80 km) and the conditions of no one of them cannot be compare with the chosen place - Sumgayit and Artem are near to seacoast and Mashtaga is not far from it. It is possible to consider a plane of their disposing as the same with respect to the Caspian Sea level.

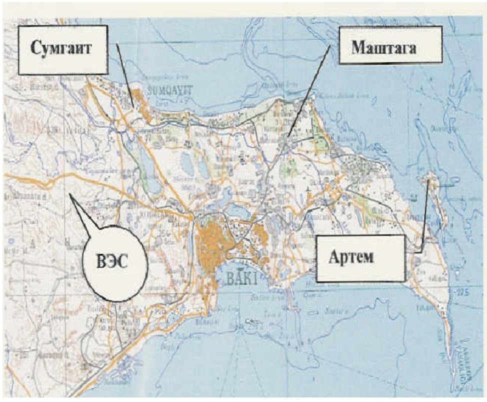

Figure 6. Location meteorological station, on which was defined first estimation wind features Gobustan.

Design data of long-term wind power values in Gobustan area with using of 20-year-old data of these weather stations are presented in a view of Weybull distribution graph (a recurrence correlation taken as a % of wind speed, m/s) (fig. 7).

According to Weybull calculation it follows that the annual average wind speed at a height of 40 m is equal to 7,82 m/s.

These data don't quite correspond to real wind potential in Gobustan area because they are based on initial data of these weather stations.
But for preliminary estimates this database is quite suitable, for they correspond to WMO norms.

The annual average wind speed in this region has been determined more precisely on a database of continuous wind speed records on a tower, installed directly in a zone of prospective WPF building under WindPRO program.

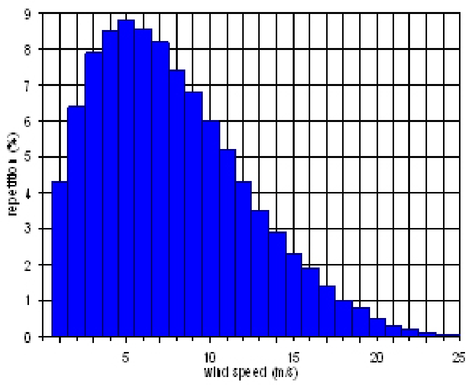

Figure 7.Graphics of the distribution Veybulla on area Gobustan.

WindPRO is the most up-to-date and applied system on WPPs and WPFs accounting and designing and serves exact estimation of a site wind potential, account of WPPs' power output, noise influence, profitability, ecological influence on an environment etc. WindPRO works jointly with WAsP system of modelling. The WPF site's lay of land is modeled with the using of digital data on topography and orography (a soil state, influence of possible available vegetation and structures, etc.), 20 meter vertical permission has been used for an estimation of local area topography around WPF site. The permission has been cut down to 50 m for close and to 100 m for remote sites.

Period of measurements: from 04/01/1999 to 03/31/2000.

Interval of the data: hourly average parameters (8760 positions).

Height of measurements: 40 and 30m.

These primary data have been entered into WindPRO program. As a result a design annual average wind speed at a height of 40m has been obtained – 8,2 m/s. The monthly average wind speed graph within a year for a Gobustan area, calculated by WindPRO program is presented in fig. 8.

Selection and comparison of optimum WPPs types on a basis of WindPRO program calculations are presented in table 3.

All studied WPPs have been compared with the help of specific parameters of electric power output, which represent a ratio of total output to installed WPPs capacity. As a result the first places have been occupied by WPPs of the firms Vestas (V80–2,0 MW) and Vensys (Vensys 62–1,2 MW). On the second place is WPP of Vensys firm (Vensys 70–1,5 MW). On the third place is WPP of Siemens (Bonus 1,3–1,315 MW). Last and penultimate places have been accordingly distributed between Nordex firm (N 60–1,3 MW) and Vestas firm (V66–1,75 MW).

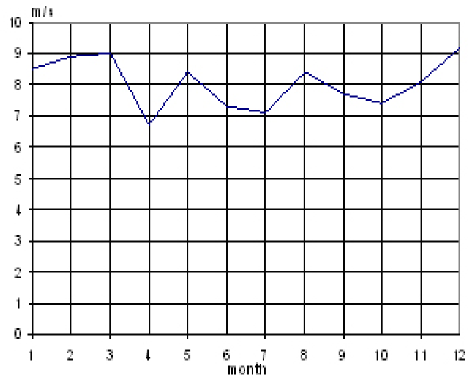

Figure 8. Monthly average graph wind speeds on area Gobustan.

Table 3.

WPP			Generation of electrical energy Wh in years		Specific param-eteres
Produ-cer	Model	Power			
		MW	Ideal	Net (18%)	MWh / kW
Vensys	Vensys 62	1,2	5040,8	4133,4	3,44*
Nordex	N 60	1,3	4600,0	3772,0	2,90
Siemens	Bonus 1,3	1,3	5101,0	4183,0	3,20
Vensys	Vensys 70	1,5	6222,0	5102,0	3,40*
Vestas	V66-1,75	1,75	6285,0	5154,0	2,95
Vestas	V80-2,0	2,0	8384,0	6875,3	3,44*

According to the data of comparative accounts their 3 the best types have been recommended, they are marked by asterisk in the table.

Let's estimate approximately the economic aspects of 50 MW WPF functioning. For WPF of 50 MW capacity the total cost is evaluated approximately as 100 million dollars, i.e. a cost of 1 kW of an installed capacity will constitute about 2000 US$.

If WPF will consist of 25 plants of Vestas V80 type with an equal to 2,0 megawatt each one capacity, then for Absheron conditions a power output (net) will total about 172 million kWh in a year (table 3).

Tariff Committee of the republic's Ministry of economic development has established a wholesale purchase price of electric power from wind power farms at a level of 4,5 gap/kWh (1 manat = 100 gapik). Without the expenses for the routine maintenance, the personnel salary and other costs the total profit from sales will constitute about 7,5 million manat (1 manat = 1,25 US dollars) in a year, to transfer into US dollars it will total about 9,4 mln.USA dollars. Thus, a pay-back period of wind power farm will be more than 10 years.

If to attract private investors, then an investor with taking into account a percent from a bank credit will determine a minimum cost of this station at 110 million dollars and a term of initial capital return will be no more than 5 years, therefore he, according to rough accounts, should refund on 22 million USA dollars in a year.

For all this the purchase price of electric power from wind power farm should constitute about 10,5 gap. for 1 kWh.

If a state incurs the obligation to pay in addition 6,0 gap. within 5 years for 1 kWh of produced electric power, then it will constitute 52,5 million manat or 65,6 million USA dollars, i.e. 13 million USA dollars in a year.

From the other hand to generate 175 million kWh at Azerenergy thermal power plants with an average consumption of 330 g/kWh of equivalent fuel, it will require 61,2 thousand tons of equivalent fuel. To transfer into fuel oil it totals about 43,7 thousand tons of fuel oil in a year. If to accept the market price of 1 ton of fuel oil equal to about 300 US dollars (the least favorable alternative), then the state will gain from a sale of the liberated fuel oil about 13 mln. USA dollars in a year.

Thus, a state can easily compensate surcharge of 6,0 gap. for 1 kWh within 5 years.

INFERENCE

1. Survey of world wind-power engineering development on the extremity of 2009 has demonstrated unprecedented rapid growth of this power engineering branch - over the last 10 years the installed capacity has increased in 10 times. Quintuple of leaders was defined - USA, China, Germany, Spain and India.

2. Absheron peninsula with a coastal zone of Caspian Sea is a high potential region according to wind performances. The yearly average wind speed in this region at a height of 40 m is within the limits of 7,5 – 8,5 m/s.

3. A preliminary feasibility study of 50 MW wind power farm building (first stage) on Absheron (Gobustan) has allowed to confirm reasonability of its position, an expected electric power output and optimum selection of wind power plants type.

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In Currently, he is a Professor of Power Engineering and head of "Wind power" laboratory in Azerbaijan Scientific-Research and Designed-Prospecting Institute of Energetics. He is also an academician of International Academy of Electrotechnical Sciences (Moscow). He is an author or coauthor of many papers (above 170) in journals and international conference proceedings.

Laman Hasanova - was born in Baku, in September, 4, 1975. She graduated from Azerbaijan State Oil Academy on the speciality of electrician engineer and got Bachelor's degree in 1999 and Master's degree in 2001. In 2009 she got the Ph.D. degree in Azerbaijan Scientific-Research and Designed-Prospecting Institute of Energetic. She is a coauthor of a book on Renewable Power Sources and an author of several papers.

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DISTRIBUTED SYSTEM FOR SOLUTION OF PLANNING AND CONTROL PROBLEMS IN POWER INTERCONNECTIONS

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Abstract. This paper presents the principles and foundations, on which construction and functioning of distributed system destined for optimal control of large power interconnections is based. Such power interconnections consist of power systems of independent countries and independent markets of electricity. Solution of optimization problems in large power systems according to these principles is carried out as coordinated solution of optimization problems of two levels: optimization problems of subsystems on lower level and optimization problem of upper level – determination of optimal power flows between subsystems. This organization of solution of optimal operation problems forms the basis for creation of efficient distributed control system providing global optimality of large power interconnections and self-determination of independent power systems. Hierarchical algorithm for solution of power flow problems, which can be implemented in this control system, is also presented in the paper.

Keywords: Parallel and Distributed Control Systems, Hierarchical Models, Large Power Systems, Power Flow, Optimal Power Flow.

1. Introduction

One of the most important problems in development of modern control systems for large power interconnections is that that they should provide for global optimality of functioning of these interconnections and at the same time ensure self-determination and conditions for internal optimality of decisions taken at the level of independent countries and local electricity markets.

Existent organization of operation control system in these interconnections consisting of independent system operators, solving the problems of planning and dispatching in their own power systems and coordinating interchange of power and energy between power systems, makes it possible to achieve internal optimality of operation in each of power systems but cannot assure global optimality of functioning of these interconnections.

Practicable and most promising way for enhancement of economical efficiency in these interconnections lies in addition of one more layer to the existing structure of power systems control centers in UCTE, USA, Canada and CIS. The function of this upper layer should be calculation of optimal power flows between large power systems of these countries. Internal optimality of operation within power systems still will be provided by existing control centers of power systems.

Structure of distributed control system based on this concept and intended for realization of planning, dispatching and controlling functions in large power interconnections is presented on Fig.1. This system consists of lower layer computers, located in control centers of power systems and upper layer computer (server). Lower layer computers solve the problems of optimal control in power systems, whereas the upper layer computer determines values of optimal power flows between power systems.

This system realizes the principle of conservation of existing structure of control centers with addition to it of upper layer structure comprised of upper layer computer connected by

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communication channels with lower layer computers. This system is protected by Patents of Invention of Russian Federation and US. See [1] and [3].

Functioning of the distributed control system in solution of planning and control problems of large power system is based on the method of functional modeling (FM).

The main principles of the FM method, presented in [4] and [7] are as follows.

1. Representation of a technical system as a set of subsystems, adjoining each other in boundary nodes.

2. Building of a model as a hierarchical structure, consisting of interconnected systems of equations. In this structure subsystems are represented by lower level systems of equations. A higher level system of equations represents borders between subsystems (boundary nodes).

3. Representation of subsystems on the higher level of model by functional characteristics (FCs). FCs are input-output characteristics in which vectors of boundary variables of one kind are considered as input variables and boundary variables of another kind as output variables. These characteristics are obtained while meeting all constraints within subsystem.

4. Determination of the values of boundary variables on the higher level of the model through formation and solution of the system of connection equations (SCE), obtained from general expressions for boundary variables, pertaining to all boundary nodes.

Below it is shown how these principles are applied to solution of power flow and optimization problems.

2. Hierarchical FM algorithm for solution of power flow problem

The FM algorithm for solution of a power flow consists of the following steps [6], [5],[4].

1. Setting of all voltages at internal nodes of subsystems to starting value.

2. Calculation of the voltages at boundary nodes, corresponding to the voltages at internal nodes set in the previous step.

Phase angles and voltage magnitudes at boundary nodes are calculated according to the following formulas

$$\begin{aligned} \theta_b &= arctg\tfrac{U_1 \sin\theta_1 + U_2 \sin\theta_2}{U_1 \cos\theta_1 + U_2 \cos\theta_2}, \\ U_b &= \tfrac{1}{2}\sqrt{U_1^2 + U_2^2 + 2U_1U_2\cos(\theta_1 - \theta_2)}, \end{aligned} \tag{1}$$

where indices 1 and 2 refer to internal nodes belonging to the same line as the boundary node b.

3. Calculation of the active and reactive power at each internal node of all subsystems. These values should be subtracted from the scheduled values and the resulting mismatches stored in a vector for each subsystem. (The next step should be taken only if these mismatches exceed a fixed number $\acute{\varepsilon}$.)

4. Check for completion of the iteration process.

On this step the fulfillment of the conditions

$$\begin{aligned} \max \Delta P_i \le \varepsilon, \\ \max \Delta Q_i \le \varepsilon, \end{aligned} \tag{2}$$

is checked out.

5. Formation for each subsystem of a linear system of equations representing it on the first iteration and subsequent determination of the FC of subsystem from this linear system.

This linear system looks as follows

$$\begin{vmatrix} \Delta\dot{S}_i \\ \Delta\dot{S}_b \end{vmatrix} = \begin{vmatrix} A_{ii} & A_{ib} \\ A_{bi} & A_{bb} \end{vmatrix} \begin{vmatrix} \Delta\dot{U}_i \\ \Delta\dot{U}_b \end{vmatrix}, \tag{3}$$

where $\Delta\dot{S} = |\Delta P \Delta Q_1|^t$; $\Delta\dot{U} = |\Delta U \Delta\theta|^t$.

In (3) $\Delta\dot{S}_i$ is the vector of active and reactive power mismatches in internal nodes found on the previous step.

Applying the Gaussian elimination of internal variables to (3) we obtain

$$\left| \begin{array}{c} \Delta\dot{S}'_i \\ \Delta\dot{S}'_b \end{array} \right| = \left| \begin{array}{cc} A'_{ii} & A'_{ib} \\ 0 & A'_{bb} \end{array} \right| \left| \begin{array}{c} \Delta\dot{U}_i \\ \Delta\dot{U}_b \end{array} \right|. \tag{4}$$

The vector $\Delta\dot{S}_b$ in (3) should be set equal to zero before this elimination. Accordingly the vector in (4) is the vector of constant terms appearing in the place of this zero vector in the process of elimination.

From (4) follows that the FC of subsystem is

$$\Delta\dot{S}_b = A'_{bb}\Delta\dot{U}_b - \Delta\dot{S}'{}_b, \tag{5}$$

where $\Delta\dot{S}'_b$ is a vector of constant terms, $\Delta\dot{S}_b$ and $\Delta\dot{U}_b$ are considered as vectors of unknown variables.

6. Formation and solution of the SCE, which is regarded as a higher level system of equations in this algorithm.

Formation of the SCE is executed in this algorithm by way of substitution of expressions in the right hand side of the FCs (5) into following system of equations for active and reactive powers crossing the boundary nodes

$$\Delta S_{bI} + \Delta S_{bK} = U. \tag{6}$$

Substitution of the expressions in the right hand side of (5) into (6) for all boundary nodes gives

$$A_s \Delta U_b^s = \Delta S_b^s. \tag{7}$$

Solution of this SCE gives values of increments of voltage angles and magnitudes in boundary nodes of subsystems.

7. Calculation of the increments of voltage angles and magnitudes in internal nodes of subsystems by substitution of subvectors of boundary variables found in previous step into equations (4) and performing backward Gaussian move in these equations.

8. Return to step (2)

3. Hierarchical FM algorithms for solution of optimization problems

If the FM method is applied to solution of economic dispatch problem in large power system this system should be represented as a set of subsystems adjoining each other. If power flows through boundary nodes of subsystems are considered as boundary variables and there is only one boundary node between each pair of adjoining subsystems Lagrange function for this model can be constructed as a sum of Lagrange functions of subsystems in following form

$$L_s = \sum_I \sum_i F(P_{iI}) + \sum_I \left[\lambda_I \left(P_{LI} - \sum_{iI} P_{iI} + \sum_{bI} \pm P_{bI} \right) \right], \tag{8}$$

where P_{il} is the power of the station i in the subsystem I , P_{bI} is the power flow through the boundary node b adjacent to the subsystem I, P_{LI} is the power consumed in the subsystem I.

Note that P_{bi} enters this function with sign + for one subsystem and sign – for adjacent subsystem.

Necessary condition for an extreme value of the objective function (8) can be obtained taking the first derivative of (8) with respect to each of the boundary variables and setting these derivatives equal to zero. It results in the following set of equations

$$\lambda_{Ib} - \lambda_{Jb} = 0 \qquad\qquad b = 1, \ldots, nb \,, \tag{9}$$

where index I_b denotes for one of subsystems adjacent to the boundary node *b,* and J_b denotes for another.

Each of equations in (9) applies to one of the boundary nodes between subsystems in this model and total number of these equations is equal to the number of these nodes.

The systems of internal equations, representing the minimum cost operating conditions for subsystem I if network losses are not taken into account look as follows

$$\frac{dF_{iI}}{dP_{iI}} - \lambda_I = 0, \tag{10}$$

$$P_{LI} - \sum_{iI} P_{iI} + \sum_{bI} \pm P_{bI} = 0. \tag{11}$$

Upper equations in this system are obtained from the condition that the first derivatives of the fu nction (8) with respect to internal variables P_{iI} should be equal to zero. Eq. (11) is the constraint equation of subsystem I (balance of power equation).

Finding expressions for the first derivatives of the cost functions of stations we can present Eq. (10) in explicit form

$$a_{iI} P_{iI} + b_{iI} - \lambda_I = 0. \tag{12}$$

In this case it is assumed for simplicity that the cost function has the form of a quadratic function.

Solution of the economic dispatch problem by the hierarchical FM algorithm consists of the following steps.

1. *Formation of Eqs. (10), (11) and determination of the FCs of subsystems.* Applying the Gaussian elimination of internal variables (i.e. P_{iI}) to the system (10), (11) for each of the subsystems the FCs of subsystems should be determined, having the following form

$$\lambda_I = a_I \sum_{bI} \pm P_{bI} + c_I. \tag{13}$$

2. *Formation and solution of the SCE.* Substituting for λ_{Ib} and λ_{Jb} from right-hand side of Eq.(13) for FCs of the subsystems I and J (adjoining to boundary node b) into Eq. (9) yields one of the equations, forming the SCE. In this way equations for all boundary nodes should be obtained. Set of these equations forms the SCE shown below

$$AP_b = b. \tag{14}$$

Solution of this linear system gives optimal values of power flows between subsystems.

3. *Determination of power outputs of stations in subsystems.* **S**ubstituting the values of optimal power flows on the borders of subsystems into Eq. (13) gives the values of Lagrange multipliers λ_I in subsystems. Then back substituting λ_I into Eq. (10) optimal power outputs of stations in subsystems should be found. These values are exactly the same that can be obtained by basic one level algorithms for solution of this problem.

Hierarchical algorithms of this type are now developed for all basic optimization algorithms.

4. Distributed system for dispatching of generation in large power systems

General structure of the FM algorithms and principles of the FM method constitute a basis on which construction and functioning of distributed control systems intended for optimal control of large integrated electrical power systems can be founded. These large power systems (interconnections) consist of power systems of independent countries and independent markets of electricity. The most important problem, which should be solved in creation of such system is the necessity to combine in it on the one hand the ability to achieve global optimality of interconnection as a whole and on the other hand the ability to maintain self-determination and local optimality of power systems of independent countries. This problem can be solved in distributed control system having hierarchical structure and containing computers, belonging to different hierarchical levels of the system.

Figure 1 shows the configuration of this system.

In solution of power flow and optimal power flow problems (as well as other optimization problems) this system operates in each iteration in following way.

1.Formation of systems of equations for subsystems and determination of their FCs is executed concurrently by computers of lower level, placed within the limits of each subsystem.
Data on parameters of FCs of all subsystems are delivered from computers of lower level to computer of upper level (server).

2.Formation and solution of the SCE is executed by the computer of upper level. Data on the values of boundary variables are delivered to the computers of lower level.

3.Calculation of the values of internal variables of subsystems is executed concurrently by computers of lower level.

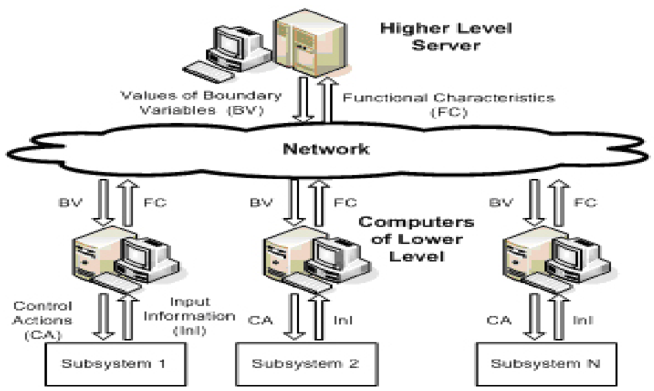

Figure 1. Configuration of the distributed control system.

Important features of this control system are the following.

1. All calculations on the lower level of the system are executed concurrently by computers of lower level.
2. Convergence of iteration processes in the algorithms working in this system is the same as in the corresponding basic algorithms.
3. Data delivery between computers in this system is limited to delivery of data on FCs and boundary variables. No data on internal parameters and internal state of subsystems of power system should be transferred from subsystems.

Optimal operation of large interconnections is based in this control system on coordinated solution of optimization problems of two levels: optimization problems of subsystems on lower level and optimization problem of upper level – determination of optimal power flows between subsystems.

This distributed system can be used not only for solution of optimization and control problems of large power systems but also for solution of power flow and state estimation problems in these systems if hierarchical FM algorithms are implemented for this purpose.

5. Conclusion

Hierarchical structure of the power system model described above corresponds to representation of large power interconnection as a set of interacting power systems (independent agents of upper level). By definition the FCs of subsystems (independent power systems) are input-output characteristics obtained while meeting all optimality equations and constraints within subsystems. From economical point of view these characteristics represent relationships between prices of energy (marginal costs) and amounts of energy traded between power systems when optimal control of generation within power systems is carried out.

When FCs of subsystems are known the SCE in hierarchical model can be formed. This upper level system of equations can be considered as mathematical formulation of the problem of determination of optimal power flows between power systems (problem of the market of markets) with inequality constraints taken into account.

This distributed system has following important advantages in comparison with existing decentralized control systems and possible traditional centralized control system.

1. Great reduction in total cost of energy generation necessary for supplying all consumers of electrical energy in European Interconnection because of optimal allocation of power production between the power stations within the European Interconnection.

2. Efficient organization of distributed computational process in the course of control problem solution, reduction of data transfer and enhanced reliability.

3. Self-sufficient solution of optimal control problems in power systems and at the same time optimal operation of interconnection as a whole.

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INCREASE OF EFFICIENCY OF TECHNOLOGIES DESALINATION SALT WATER IN THERMAL POWER STATION

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Abstract. For the supply boiler of thermal power station water with high degree of clearing is required. In the conditions of deficiency of fresh water the feed water of boiler can be received by thermal or reverse osmosis desalination salt waters. For increase of efficiency of technology desalination (increases in conversion, decrease in expenses) the decision of the problem of scaling on surfaces of heating and membranes is required. In the paper discussed the efficiency of the ion exchange methods of scale control in salt water desalination systems. Waters with wide range of salinity variation from 3 to 35g/l and hardness of 10-120mg-eqv/l were tested. The technologies of *Na*-, *Mg-Na*-cation exchange and *Cl*-, *Na-Cl*-ion exchange were studied. Developed equations for computing the ion exchange process output data and proposed new regeneration techniques, which allow deep removal of scale forming ions to the residual hardness 3-5μg-eqv/l. For reverse osmosis systems the scheme desalination salt waters with concentrate use as for softening initial water, that and permeate is offered. Developed technological schemes for complex treatment of saltwater and utilization of reject brine of desalination units. Efficiency of large scale desalination on the basis of thermal power station is proved. The detailed analysis work of industrial desalination plant with ion exchange softening are given.

Keywords: Salt Water, Scale Formation, Ion-exchange, Complex Treatment, Reverse Osmosis.

1. Introduction

Desalination salt water is currently one of the most imresinte problems. According to the UN data 43 countries of the world experience shortage in fresh water supply. A number of regions of Azerbaijan do not have adequate fresh water resources, especially the Apsheron Peninsula with high density of population and industries. Significant amounts of fresh water resources are used for water supply of industries in the region. Currently, improvement of ecological performance of desalination technology has acquired a great importance. Besides, there is a great demand in multipurpose utilization of salt waters in such sectors as power engineering, oil extraction and refinery. Along with aforementioned, the issues of complex treatment of salt waters, desalination (Zero-Discharge Processes) with co-production of chemicals of high quality are still important.

2. Literature Review

Efficiency of thermal and reverse osmosis methods of seawater desalination is dependent on solution of scale and depositions control problems and first of all that of calcium sulfate [6,8,13,14]. Solving this problem allows to increase the input temperature of distillation, the number of concentration stages and concentration factor, to use evaporators from cheaper carbon steel, and to minimize the quantity of reject brine. Increase of the input temperature from 110 to 180^0C allows reducing cost of desalination by 20-40% [13]. In two-purpose power plant increase of distillation temperature causes the efficiency coefficient to rise and to reduce the specific exergy demand. Traditional ways of preliminary processing of salt waters (acidation, introduction antiscalent) allow spending process desalination with size of conversion no more than 20-40%

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[6]. Antiscalent's are subject to thermal decomposition at temperatures 100^0C and above. Besides, antiscalent's as a part of concentrates are dumped in the sea and cause an environmental damage.

According to [5,6] more effective method of prevention scale formation is preliminary ion-exchange softening sea water with concentrate use (a residual brine desalination) for regeneration cationite. In this case in the sea the salts arriving with initial water are dumped only. Possibility of increase of conversion to 60-80%, decrease in expenses for 30-40% rises.

Analysis of options to solve the shown issues revealed the exceptional role of ion exchange methods (*Na-,Mg-Na*-cation exchange and *Cl*-, *Na-Cl*-ion exchange) applied before desalination. However, the research has been done only for separate types of water, mainly of the Caspian Sea. [6]. *Na*- and *Mg-Na*-cation exchange technologies have been studied quite comprehensively, but the *Cl*-anion exchange have been studied very scarcely.

The main technological parameters on the *Na*- and *Mg-Na*-cation exchange processes are the working exchange capacity and the residual hardness of the softened water. Analytical models to compute those parameters are not precise and quite complicated. In [6] given the following simpler equations to compute the shown parameters.

$$E_w = \alpha_e \cdot E_{eq} \cdot (1 - \sigma_{pl}\frac{d_{pl}}{d_0}), g - eqv/m3, \tag{1}$$

$$C_r = k\frac{f_{Mg,r} \cdot (f_{Na,s})^2}{(f_{Na,r})^2 \cdot f_{Mg,s}}(\frac{C_0}{C_r})^2, mg - eqv/l, \tag{2}$$

where E_w - working exchange capacity of cation resin; α_e- efficiency coefficient of cation resin regeneration; E_{eq} - equilibrium exchange capacity (total exchange capacity at equilibrium taken by total hardness in *Na*-cation exchange and by calcium ions in *Mg-Na*-cation exchange), $g - eqv/m^3$; d_{pl}, d_0- the depth of the protection bed and total depth of cation resin, m; σ_{pl} - coefficient counting the degree of use of full exchange capacity of cation resin in the protection bed; $f_{Na,y}$, $f_{Mg,y}$, $f_{Na,r}$, $f_{Mg,r}$ - activity coefficients of the ions in softened water (s) and regeneration brine (r); C_0, C_r - the sum of cations in input water and regeneration brine, $mg - eqv/l$.

But these equations can not be applied to compute parameters of cation exchange processes of salt water of any composition. Therefore, in the article considered the issues of ion exchange treatment of salt waters with salinity variation in wide range, which are characteristic for the region's sea water and ground water: Salinity range $3 - 35g/l$, hardness $10 - 150mg - eqv/l$, sulfates $5 - 100mg - eqv/l$, chlorides - $40 - 450mg - eqv/l$, bicarbonates $2 - 10mg - eqv/l$ and additional equations have been developed to comprise waters salinity variation in shown range.

The study of issues of utilization of reject brine of desalination units and technologies of complex treatment of salt water [10,11] have revealed that because of close solubilities of $NaCl$ and Na_2SO_4 their separation into single products is complicated and can be achieved only by using complex technologies. Therefore, one of objectives of this study has been development of more efficient technologies of complex processing of salt waters with ion exchange.

3. Results and Discussion

3.1. **Ion exchange treatment of salt waters.** The main results of application of ion exchange technology before desalination are the lower cost and higher degree of water treatment.

Those advantages are achieved by using of:

– own salt compounds of the salt water in reject brine of desalination unit for regeneration of ion exchange resins;
– ion exchange columns used for treatment of fresh water;
– new techniques of regeneration and sorption.

To achieve the higher degree of removal of scale forming ions, especially that in highly salt water (salt content more 8-10g/l) it is necessary to use counter current regeneration.

Note that the purpose of *Mg-N*a-cation exchange process is to remove only calcium cations and regeneration of the cation exchange resin with the sum of magnesium and sodium salts of the reject brine of evaporators or a reverse osmosis unit.

The initial experiments on *Na*-, *Mg-Na* cation exchange were done on the dynamic column with 3 sm in diameter, loaded with *KY-2* strong acid cation exchange resin with depth 1,5 m. Counter current regeneration was done with the concentrate of water treated by the ion exchange with total concentration *2N*. In case of Na-cation exchange the regeneration brine contained mixture of *NaCl* and Na_2SO_4 salts and in case of *Mg-Na*-cation exchange mixture of salts of *NaCl*, Na_2SO_4, $MgCl_2$, $MgSO_4$. The following results has been obtained:

– working exchange capacity of cation exchanger was determined by Mg^{2+} breakthrough in *Na*-cation exchange process and by Ca^{2+} breakthrough in *Mg-Na* cation exchange (E_w);
– specific water production (amount of water for $1m^3$ of cation resin);
– residual concentrations of Ca^{2+} and Mg^{2+};
– quantity of salts in input water, which can be used for regeneration (g).

Experiment results are given in the table 1.

The data from the table show quite high efficiency of the considered technologies: the working exchange capacity of *KY-2* cation resin vary from 800 to 1200 g-eqv/m^3 in *Na*-cation exchanger and from 300-680 g-eqv/m^3 in *Mg-Na*-cation exchange process. The residual concentration of cations in the *Na*-cation exchange process caused only by presence of Mg^{2+} cations. Its concentration varies in range from 0,02 to 0,9 mg-eqv/l, which means 99% removal of hardness ions. Such a deep softening provides absence of deposits in the desalination units even at high temperatures (200^0C and more) and concentration factors.

Table 1. Technological parameters of the *Na*- and *Mg-Na*-cation exchange processes for some types of salt waters.

	Input water			g,g-eqv/m^3	E_w,g-eqv/m^3	d,m^3/m^3	$\tilde{N}^{rez}_{Ca}$	$\tilde{N}^{rez}_{Mg}$
	C_{Na}	C_{Ca}	C_{Mg}				mg-eqv/m^3	
1	50	5	5	4/7,7	1000/640	50/128	0,0/0,05	0,02/2
2	100	10	10	5,6/6,7	940/560	47/56	0,0/0,15	0,08/6
3	170	15	15	6,6/8,4	990/680	33/46	0,05/0,20	0,25/8
4	138	16	60	4/7	1200/525	16/33	0,05/0,20	0,3/48
5	248	13	59	4,4/9,9	980/400	13,6/31	0,1/0,35	0,5/40
6	470	20	110	4/11	800/300	5,4/15	0,2/0,6	0,9/75

Note: nominator-for *Na*- cation exchange, denominator for *Mg-Na* cation exchange.

As it seen from the table increase in salt content of input water causes the parameters of ion exchange to decline. It affects *Na*-cation exchange in greater degree.

Therefore for water with higher salt content the *Mg-Na*-cation exchange process is more preferable. Besides, we can not state that the *Na*-cation exchanger is unapplicable for the ocean water. In this case, cost of ion exchange treatment will be higher.

Seawater contains HCO_3^- ions, which are the reason of formation of alkali scale. Therefore, in *Mg-Na*-cation exchange processes the decarbonization of water is necessary to reduce content of HCO_3^-- to $0,05-0,2mg-eqv/l$ dependent on temperature, magnesium concentration, and other factors. Deep decarbonization of water is related to certain difficulties. In *Na*-cation exchange treatment of water the deep decarbonization of the input waters is unnecessary. But due to high concentrations of OH^- and CO_3^{2-} in reject brine it should be neutralized. Otherwise, it will cause precipitation of $Mg(OH)_2$ and $CaCO_3$ in exchanger bed during regeneration. However, the quantity of acid will be less than if acid added to input water, because it is only needed to neutralize OH^- and transform CO_3^{2-} into HCO_3^-.

For direct feed of boilers with softened salt water it is important to study the issues of seawater softening in the polishing column. Experimentally studied the softening process of Caspian seawater to the residual hardness $0,2-2mg-eqv/l$ on weak acid cation resins sulfonated coal and strong acid cation resin *KY-2*. The regeneration was done with acidified reject brine of evaporators. In was determined that the residual hardness can be reduced to $15-20\mu g-eqv/l$ on sulfonated coal and $20-30\mu g-eqv/l$ on *KY-2* providing high salt spent- $15-20g-eqv/l$ of cation resin. The exchange capacities were respectively $10-50$ and $10-80g-eqv/m^3$ cation resin.

For deeper softening to the residual hardness of $5\mu g-eqv/l$ it is recommended to use polyfunctional cation resins such as sulfonated coal and KB-4. The required effect is achieved if weak acid groups $COOH$, which less affected with counterion effect are involved into the ion exchange. For the reason, the acid-alkali technique of cation resin regeneration was developed. In this case all required amount of acid is added to the first 30-40 % of regeneration brine and the rest 60-70 % of the brine contains CO_3^{2-} and OH^-. The results of the study of processes of co-current regeneration in polishing column loaded with sulfonated coal and *KY-2* are given in figure 1. From the obtained results we can see that on sulfonated coal complete softening occurs independently on the level of water mineralization (curve 1).

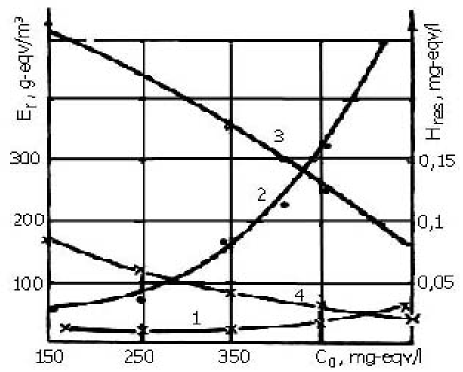

Figure 1: Working exchange capacity (1) and residual of post softened water (2) as a function of water mineralization.

For *KY-2* the increase in Ca^{2+} concentration results in sharp increase of the residual hardness (curve 2). Meanwhile, the working exchange capacity achieved on *KY-2* more than 3 times of that on sulfonated coal (curves 3 and 4). To combine the advantages of *KY-2* and sulfonated coal, it is suggested to use their mixture at the polishing column. The minimal portion of the sulfonated coal must be no less than 50 % of the total volume.

The acid-alkali method of co-current regeneration of sulfonated coal can provide the complete softening of salt waters in whole range. The value of minimal salt requirement for efficient polishing can be determined from the following expression:

$$g_{\min} = 6,67\ln\frac{1,8+3H_1}{0,01C_0-0,36} + 13,34\ln\frac{C_0}{C_r} + 35,43, g-eqv/l, \quad (3)$$

where H_1 is residual hardness of softened water after first stage. The results of calculations by this equation showed that the g_{min} varies in a wide range 6-26 g-eqv/l. With increase of H_1 and C_0 the value of g_{min} increases, but increase of C_r causes g_{min} to decrease. Such high salt requirements for regeneration of the polishing column when only own salt compounds of the input water used for regeneration can be achieved if the volume of cation exchange resin in the polishing column, depending on input water salinity, to be 10-40% of the volume of cation exchanger resin that is in the roughing column.

The processes of *Cl-* and *Na-Cl*-ion exchange are considered as the basis of new methods of scale control in the desalination units, which in a number of cases can be alternative to the *Mg-Na*-cation exchange and creates reasons for development of clean technologies of processing of sea and salt waters. The results of preliminary studies of the *Cl*-anion exchange with strong base anion exchange resin *AB-17* and weak base anion exchange resin *AH-31* are given in the table 2.

As it can be seen from the table 2 because of the counter ion effect the usable part of the full exchange capacity of anion exchangers makes up 60-70 % for salt water and reduces to 10-20 % for the ocean water. And the strong base anion exchanger is more strongly subject to that effect. At the same time the high degree of desulfatization achieved (79-99%) results from slight effect of counterions on the depth of remoral.

One of conclusions derived on basis of the current study is that it is more expedient to use *AB-17* for the desulfatization of salt waters and for waters where the concentration of SO_4^{2-} is comparable with concentration Cl^-. The latter, as known, is more characteristic for industrial mineralized water. As to seawater, the higher parameters are more characteristic for anion exchanger *AH-31*. The specific water production made up $11 - 22m^3/m^3$ versus $9 - 13m^3/m^3$ on anion exchanger *AB-17*.

Table 2. Parameters of desulfatization of salt waters with *AH-31* and *AB-17*.

	Parameters of ion exchange	Quality parameters of input water							
		9/9	18/9	27/9	$140^2/70$	$288^3/30$	$185^4/60$	$180^5/12$	$555^6/55$
1	E_w by SO_4^{2-}, $g-eqv/m^3$	10101/1057	869/587	752/540	882/630	450/270	602/420	264/160	286/170
2	δ, %	68/75	59/42	51/39	53/43	29/18	38/28	18/12	18/11
3	$C_{rem} on SO_4^{2-}$, mg-eqv/l	0,1/0,1	0,1/0,1	0,2/0,2	2,0/2,2	3,5/4,0	2,5/3,0	2,5/2,5	6,1/6,2
4	Δ, %	99/99	99/99	98/98	97/97	88/87	96/95	79/79	89/89
5	$q, m^3/m^3$	112/117	96,5/65,2	83,5/60	12,6/9,0	15/9	10,0/7,0	22/13,3	5,2/3,1
6	$g, kg/m^3$	120/123	156/103	180/126	160/110	280/167	147/100	260/149	190/110

Note: 1-numarator AH-31, denominator AB-17, 2-Caspian seawater, 3-Black seawater, 4 - Azov seawater, 5-Baltic seawater, 6-ocean water, δ-portion of exchange capacity, Cres-residual concentration of SO_4^{2-}, Δ – degree of desulfatization.

It is known that the degree of dissociation of functional groups of weak base anion exchange resin is strongly *pH* dependent. The anion exchange process parameters were studied on the Caspian seawater with *pH* correction of input water and regeneration brine. In the case of the former by the acid addition to the Caspian seawater resulted in the resudual alkalinity varied in range $0,1 - 3mg - eqv/l$. The *pH* of regeneration brine was maintained at the level 1,2-1,7 by acid addition. In the table 3 given the results of experiments on co-current and counter current *Cl* - anion exchange treatment of Caspian seawater. As it can be concluded from the data on the table 3, co-current method of regeneration without any correction of the *pH* of regeneration brine is characterized with working exchange capacity $830 - 850g - eqv/m^3$ and rather high values of residual concentration of sulfate and bicarbonate ions. Increase in acidity of regeneration brine, however, results in increase of exchange capacity.

Thus, countercurrent regeneration achieves the higher technological parameter: the residual alkalinity reduces to $0,15-0,2mg-eqv/l$, and concentration of sulfate ions to $0,7-0,9mg-eqv/l$. E_{SO4} value increases to $1150g-eqv/m^3$, and E_{HCO_3} to $65g-eqv/m^3$. Data from experiments with acid addition to process water (5-9) show even greater exchanger capacity of anion exchanger up to $1250g - eqv/m^3$. Comparison of studied technologies of anion exchange treatment shows its advantages for processing of acid added seawater with residual alkalinity $0,1-02mg-eqv/l$ and *pH=4,5-5*. This method eliminates disadvantages of acid method related to strict requirements to acid doze control to prevent corrosion of equipment because of possible overdosages.

Table 3. Results of experiments on Cl-anion exchange of Caspian seawater.

	Ac	Al	pH	Co-current		Counter current	
				E_{SO_4}/E_{HCO_3}	C_{SO_4}/C_{HCO_3}	E_{SO_4}/E_{HCO_3}	C_{SO_4}/C_{HCO_3}
1	0	3,5	7,8	830/25	3,0/1,2	850/45	1,5/0,4
2	20	0	1,7	900/25	3,0/1,0	970/58	0,9/0,2
3	40	0	1,4	1000/30	2,5/1,0	1020/60	1,0/0,1
4	60	0	1,2	1100/35	2,5/1,0	1150/65	0,8/0,1
5	0	0,2	4,0	1050/30	3,0/0,15	1280/-	0,8/0,1
6	0	0,4	5,2	1020/30	3,1/0,25	1170/-	0,6/0,1
7	0	1,1	5,8	950/25	3,1/0,30	1150/-	0,7/0,1
8	0	2,1	6,4	950/25	3,2/0,45	1120-	0,7/0,2
9	0	3,0	7,1	920/25	3,3/0,50	1090-	0,7/0,3

Note: acidity (A_s), alkalinity (Al), residual concentrations of sulfate ions (C_{SO4}) and bicarbonate ions (C_{HCO3})$-$ $in\ mg - eqv/l$.

The main problem of any ion exchange technology is to develop models, which allow forecasting the technological parameters of processes in dependence on input water composition, and conditions of regeneration and sorption. To develop models compraising a wide range of salt waters one more equation should be added to equations (1,2), which characterize relation between ionic composition of process water and available specific salt requirement (g) for regeneration. For this purpose, the following analytic equation is offered, which was developed on the basis of material balance of salts contained in water.

$$g = k_r \cdot (E_r \frac{C_0}{H} - d_w \cdot C_0) \cdot 10^{-3}, g - eqv/l, \tag{4}$$

where k_r -coefficient taking into account increase of regeneration brine consumption due to repeated use –1,1-1,5; d_w - specific water consumption for washing of cationic resin - $1,5 - 1,8m^3/m^3$ in countercurrent regeneration and 2,0-2,3- in co current regeneration; H –total hardness in Na-cation exchange and calcium hardness in Mg-Na cation exchange. Besides, for the intermediate variables on the right sides of expression (1) and (2) it was necessary by means of statistical methods and planing the experiment to yield system of relationships describing the effect of independent variables – the basic hydrodynamic concentration factors, specific regeneration brine consumption, and ionic composition of water on these intermediate variables (E_{eq}, h_p, etc) and by that on target functions E_w and C_{res}.

The models given in these works allow solving wide range of applied tasks. Applied to the Caspian Sea water with known ionic composition $(C_{Na} = 136, C_{Ca} = 16, C_{Mg} = 60, C_{SO_4} = 68, C_{Cl} = 140, C_{HCO_3} = 4mg - eqv/l)$ the model transforms into a system of the following expressions:

$$E_w = 851 \cdot g^{0,28} \cdot (1 - \frac{0,076 \cdot \upsilon^{0,52}}{h_0}), g - eqv/m^3, \tag{5}$$

$$H_{res}^{cc} = 160,9 \cdot e^{-0,6 \cdot g} (\frac{212}{C_r})^2, mg - eqv/l, \tag{6}$$

$$H_{res}^{ctc} = 639 \cdot e^{-0,28 \cdot g} (\frac{212}{C_r})^2, mg - eqv/l, \tag{7}$$

$$g = k_r \cdot (2,79 \cdot E_w - 381,6) \cdot 10^{-3}, g - eqv/l, \tag{8}$$

where $H_{res}^{cc}, H_{res}^{ctc}$ are the residual hardness of softened water respectively co current and countercurrent method of regeneration.

The model allows by computer simulation easilystudy the effect of input factors on the technological parameters of Na-cation exchange process. One of the advantages of this model is that the model allows to forecast the values of the technological parameters of the process for conditions, which can not be achieved in laboratory, for instance, the depth of resin of 3-6m, which is of practical interest in large softening and desalination installations.

The peculiarity of this model is that the exchange capacity of cation resin and the residual hardness of softened water are functions of specific salt consumption for regeneration-g, which in turn depends on the value of E_w , because the regeneration is to be done only with own sodium salts of seawater. Therefore it is suggested to compute using the method of subsequent iterations.

1. In first iteration the value E_w is accepted equal to 70 % of total exchange capacity of resin at equilibrium, which according [11] is $1414g - eqv/m^3$ ($E_w = 1000g - eqv/m^3$);

2. H_{res} and g are computed by expressions (6-8) on the basis of accepted values of h_0, V, K_r, C_r and the regeneration method;

3. For obtained value of g in second iteration calculate the values of E_r and H_{res} ;

4. The calculations stop when the E_r reaches a certain, given in advance value.

The method can be easily simulated. The process parameters varied in following ranges: $h_0 = 1,6m, V = 5 - 25m/hour, K_r = 1,0 - 1,4, C_r = 1600 - 2200mg - eqv/l$. As it seen from the results given in figure 2, the depth of cation resin significantly affects E_w when it less than 3m (a). When $h_0 = 4m$ the working exchange capacity E_w reaches $1200g - eqv/m^3$ and independent on exhaustion velocity (b). The residual hardness of output water is also dependent on the resin depth through E_w and g. It varies in range of $2,5 - 3,3$ $mg - eqv/l$ in co current regeneration $(h_0 > 2)$. Note that the total hardness of Caspian Sea water is 76 $mg - eqv/l$.

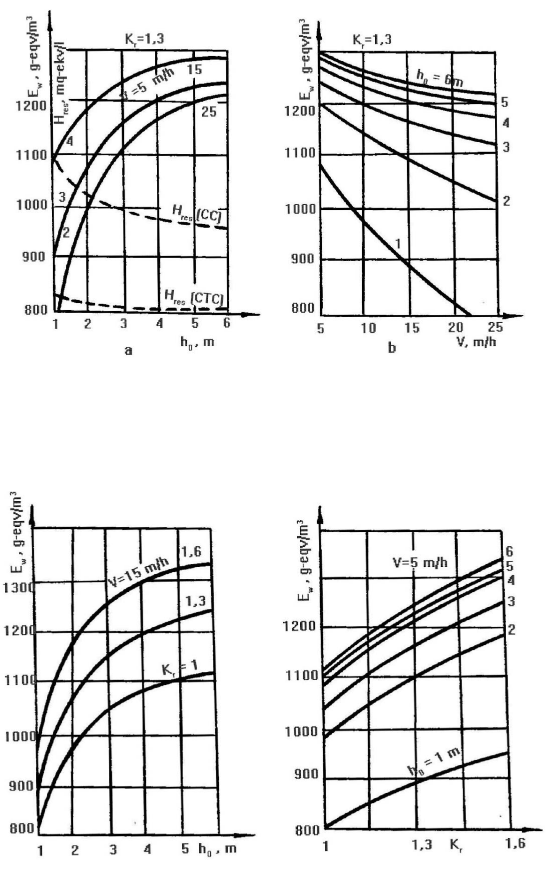

Figure 2: Technological parameters of Na-cation exchange process as a function of the main factors.

3.2. **The scheme of desalination and complex treatment of salt water with utilization of residual brines.** One of the important directions of salt water usage is preparation of water of high cleanliness for boilers of a power station [9]. This water should have specific electric conductivity of *0,5 mkSm/sm* for boilers with pressure *24 MPa* and *2 mkSm/sm* – for boilers with pressure *14 MPa*. On figure 3 the scheme of reception high-purity salt waters is presented. It is based on *Na*- cation exchange desalination the clarified water, reverse osmosis (RO) and deep desalination permeate by a method electro deionization (EDI).

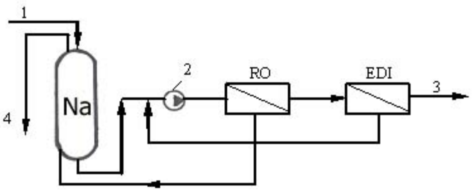

Figure 3. Function scheme of reception of high-purity salt water. 1 - clarified water; 2 - the high pressure pump; 3 - high-purity water; 4 - waste a solution.

According to data [12] important condition of effective work of modules EDI is absence of ions of hadness and gases CO_2 in permeate. It can be reached only preliminary deep softening waters by Na - cation exchange. Observance of the specified conditions provides high size of conversion of stage EDI: 90-95 %. For water of Caspian sea the general conversion reaches 60-65 %.

For preparation of additional water of boilers of average pressure(P=*2-7 MPa*) the scheme resulted on figure 4 [1,2] is offered. For these boilers water with specific electric conductivity <450 mkSm/sm and residual hadness of $3 - 5mkg - ekv/l$ is required. Such rigidity can be received by Na- cation exchange desalination permeate RO (Na_2) with use of concentrate RO for regeneration cationite. This concentrate can be used for partial desalination initial water (Na_1) that will allow reducing the expense of acid or antiscalent several times.

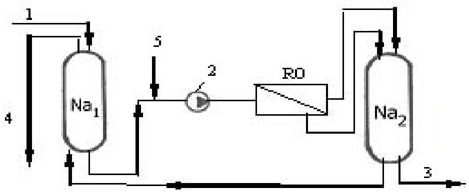

Figure 4. The scheme of preparation of additional water of boilers of average pressure. 1 - 4 - on figure 3, 5 - acid or antiscalent.

Since separation of aqua-salt system $NaCl - Na_2SO_4 - H_2O$ into separate compounds is complicated it is offered new method to transform it into more convenient system for separation $NaCl - CaCl_2 - H_2O$. The latter is advantageously different due to big difference between solubilities of the salts ($NaCl - 39,4, Na_2SO_4 - 42,3, CaCl_2 - 158$ grams in 100 gram of H_2O at 100^0C).

For utilization of spent brines of desalination of water containing sulfate and chloride ions offered method based on the following physico-chemical processes [3]:

- deep desulfatization of spent brine by $CaCl_2$
- Mg precipitation from the desulfated brine by lime, which causes a new aqua-salt system to be formed.
- thermal separation of the system $NaCl - CaCl_2 - H_2O$ in to single products.
- use of apart of $CaCl_2$ for desulfatization of brine.

The described method is realized according to the technological diagram given in figure 5.

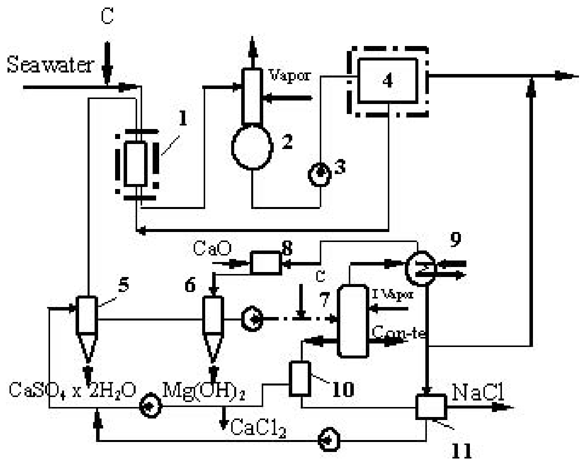

Figure 5: Principle technological scheme of realization of the method of complex treatment of salt waters.

The scheme consist of ion exchange (1), deaeration (2), desalination (4), and assumes use of reject brine for regeneration of ion exchange resin and separation of single products $CaSO_4$ x $2H_2O$, $Mg(OH)_2$, *NaCl*, $CaCl_2$ from spent brine. Utilization of spent brine includes $CaCl_2$ application to precipitate the gypsum (5), lime application to precipitate $Mg(OH)_2$ (6), concentrating (7) of new formed system $H_2O - CaCl_2 - NaCl$ with it's separation into compounds, separation of solid phase $NaCl$ (10), condensation of secondary vapor (9), use of distillate to prepare lime suspension (8) and $NaCl$ washing (11).

It is also proposed the techniques of processing the salt waters, which allows substituting the thermal separation of the sodium salts with simpler ion exchange process.

According to the method on figure 6 [4] the mixture of de-carbonized input water and spent brine are subject to *Cl*-anion exchange and desalination, the concentrated brine is then processed to yield $CaSO_4$ x $2H_2O$, $CaCl_2$ $Mg(OH)_2$, $NaCl$ and a portion of $NaCl$ is used for regeneration of *Cl*-anion exchange resin. After separation of $NaCl$ from the brine, $Mg(OH)_2$ is separated by lime application, the residual brine (containing mostly $CaCl_2$) partially taken out from the cycle as a final product, and the amount required to maintain the balance between Ca^{2+}, and SO_4^{2-} ions directed to the precipitator of calcium sulfate, where the main portion of calcium sulfate is precipitated from the mixture by addition of spent regeneration brine.

For large scale desalination installations suggested the technological scheme of open cycle power plant with direct feed of boilers with softened seawater (figure 7). In this case all the condecate of turbines is taken away as desalination product water. While processing seawater, chemicals are separated according to one of above proposed techniques. New conditions of boilers operation on softened salt water are developed on the basis of laboratory, pilot and industrial tests.

The appropriate studies were conducted, which comprised all of inner boiler processes-vapor quality, circulation, salt deposition, heat exchange, etc.

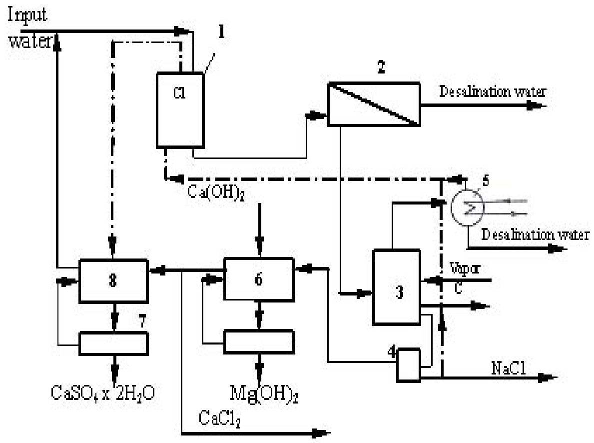

Figure 6: Principle technological diagram of complex processing of salt waters by Cl-anion exchange method. *1-Cl*-anion exchange resin; 2-Reverse osmosis unit; 3-distillation unit; 4-centrifuge 5-condencator; 6-sedimentation tanks; 7-dewatering unit; 8-precipidator.

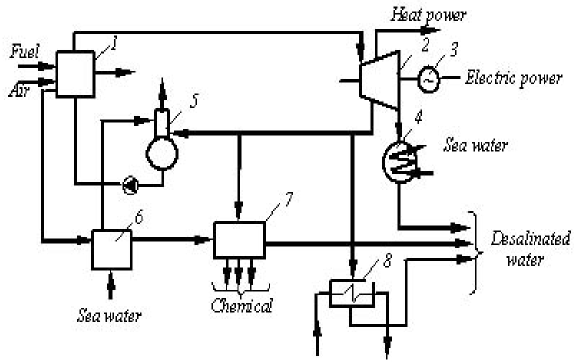

Figure 7: Principle scheme of open cycle multi pupurpose power plant. 1-boiler; 2-turbine; 3-generator; 4-condencator, 5-deaerator; 6-softener (Na-cation-exchange); 7-resedual brine complex processing unit; 8-heating system.

To the moment, there have been done several attempts for industrial application of the technologies of thermal desalination of seawater with ion exchange pretreatment. Most successful of them is one at power plant "Şimal" (Azerbaijan), which has operated during 15 years. The basic parameters of ion exchange unit are as follows:

- production water $720 m^3/day$
- working exchange capacity of KY-2 cation exchange resin $1100 - 1200 g - eqv/m^3$
- residual hardness after roughing column 0,4-0,6, after the polishing column $0,01 - 0,02 mg - eqv/l$
- water consumption for needs of installation 7-10 % of total amount of product water
- the softened water is fed to high temperature evaporators.
- The salinity of reject brine of the evaporators is $130 - 150 g/l$, which used for regeneration of ion exchange resins.

A multi-purpose desalination unit was designed for process water supply of offshore oil field "Neft Daşları". According to the project gas from the gas turbines at temperatures $425^0 C$ is used as heat source for desalination unit. The installation consist of seawater Na-cation exchange softening unit, deaerator, and multistage flash (MSF) evaporators.

The installation is two-purpose, with output of desalination product water ($340m^3/day$) and softened water ($100m^3/day$). Desalination water is used for feeding the heat net, steam-turbine station, and for watering plants. Portion of softened water directed to the cooling system of compressors.

4. Conclusions

To increase the economic and environmental performance of seawater desalination it is grounded the importance of seawater ion exchange pretreatment processes. They are preventing formation of all kinds of scale formation and allow substantial cost cutoff. Ion exchange pretreatment significantly simplifies utilization of reject brine of desalination unit and complex processing of seawater. By means of experimental studies it is proved the feasibility of deep removal of scale forming compounds by Na^- , *Mg-Na* - cation exchange and $Cl^-, Na-Cl-$ ion exchange processes. The studies comprised a wide range of brackish waters with salt content from 3 to 35g/l. The studies basically were conducted on the Caspian seawater. The expressions are yield to compute the main technological parameters of ion exchange processes. They are simple and precise enough for design purposes. They are recommended to be used in projects and design of installations. Technological schemes of preparation of a feed water of boiler of the thermal power station, based on preliminary softening salt waters are offered. Developed the technologies of seawater complex processing to yield $NaCl$, $Mg(OH)_2$, $CaSO_4$ x $2H_2O$ along with desalination of seawater. They are based on the consequences of new physical-chemical processes transforming sulfate-chloride system, which is difficult for thermal separation, into easily separable chloride-chloride system. It is also possible to substitute thermal separation of sodium salts with simpler ion exchange separation of the salts.

The efficiency of seawater desalination technology withion exchange pretreatment has been proved by reliable work of the installation at power plant "Şimal". Based on positive results design of multi purpose installation for process water supply of oil field "Neft Daşları" was implemented.

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Kamal Abdullayev was born in Hussar region of the Azerbaijan Republic. In 1956 graduated from the Baku Power Technical School, and in 1961 - Azerbaijan Oil Chemistry Institute (nowadays the Azerbaijan State Oil Academy) and got a specialty of the engineer power systems. In 1966 it he got master's degree and since 1972 is a chair of "Power system" (earlier "Water preparation, steam and gas generators and industrial the heating engineer") SOA and powerful problem laboratory functioning at it "Use sea and sewage in the industry".

In 1978 at the Moscow Power Institute he defended the thesis for a doctor's degree, and the next years under his supervision have been defended 4 doctor's and more than 50 master's theses in various directions of the theory and processing practice mineralized water and sewage. Results of scientific activity of professor K.M.Abdullayev have found the reflexion in 4 monographies, more than 10 textbooks for technical colleges, more than 300 articles and more 20 inventions.

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Now he is a professor of chair "Power system". It is awarded by a silver medal, a medal of the inventor of Azerbaijan. Field of scientific interests: technologies of prevention scale formation in systems desalination. Working out of hybrid systems desalination technologies of complex processing mineralized waters, mathematical modeling and optimization of water-desalinating systems.

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INVESTIGATION OF THE MAGNETIC ASYMMETRY OF THE THREE-PHASE POWER TRANSFORMER AT AN IDLING MODE

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Abstract. In presented article the error of capacity occurred in the result of magnetic system asymmetry of power three-phase transformers is investigated. Mathematical expression of active and jet capacities taking into account magnetic asymmetry and the geometrical sizes magnetic wiring at transformer idling have been received. On the basis of received formulas losses of capacity of the transformer from magnetic asymmetry have been estimated.

Keywords: Transformer, Magnetic Asymmetry, Voltage, Vector Diagramme.

1. Introduction

Modern electro power systems are characterised by a saturation of three-phase power transformers of different capacity. So in power system of "zerenergy" resultant capacity of power transformers makes more than 10 GVA. Therefore the decision of the questions connected with energetic efficiency and profitability of electro power systems appreciably depends on a correct choice of capacity of transformers and from their maintenance usage - economic modes of works. Despite quantitatively small value of losses from magnetic asymmetry of the individual transformer, for maintenance of their economic and effective works it is necessary to account an error and losses of capacities from magnetic asymmetry magnetic conductivity and in the presented work this problem is considered.

As it is known, power transformers are applied as the alternating current converter in electro technical installations. By means of transformers increases and voltage falls, transformation of number of phases and in some cases - transformation of frequency of an alternating current are carried out.

Transformers are used by transfer and distribution of electric energy to power installations, and also for various transformations of an alternating current to plants, in communication devices, radio, automatics, telemechanics, etc. According to it, rated power and voltage of the transformers produced at factories of the electro industry, fluctuate in very wide limits from shares volt ampere to hundred thousand kilovolt ampere and hundreds kilovolt [2].

Power transformers are classified: on working conditions - on the transformers intended for work in normal and special conditions; by the form isolating and cooling environment - on oil, dry, filled non-flammable liquid nonelectric and with cast isolation; on the types characterising appointment and the basic design - single-phase or three-phase; presence and a way of performance of regulation of voltage etc. In standards or specifications on concrete types of transformers following key parameters are specified: rated power of the basic windings three-winding transformers, rated voltage of all basic windings; losses of idling and short circuit [3].

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2. Problem statement and main results

With three-phase magnetic system magnetising currents in separate phases are not equal in transformers each other and form asymmetrical system of currents. Therefore the first harmonious phase currents are shifted among themselves on a corner which is distinct from 120^0 (fig. 1) where corners are accordingly equal to$120^0 - \alpha$, $120^0 - \alpha$and $120^0 + 2\alpha$.

In given article the transformer working in a mode of idling is considered. On figure 1 the basic scheme and the vector diagramme for the transformer are resulted at a mode of idling and in the presence of magnetic asymmetry on phase currents.

It is necessary to notice that phase primary voltage U_A, U_B, U_C form symmetric system. On the vector diagramme phase currents I_{XA}, I_{XB}, I_{XC} (figure 1) are shown also.

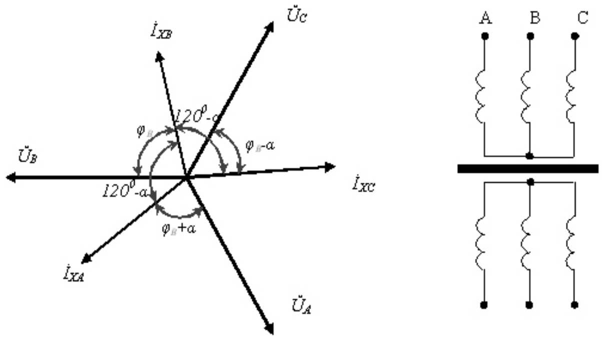

Figure 1. Shift of phases between phase currents and voltage at idling three-phase three peg of transformer

Let's admit, that voltage U_B advances current I_{XB} on corner φ_B then, apparently from the vector diagramme, current I_{XA} will lag behind voltage U_A on corner $\varphi_B + \alpha$, and current I_{XC} from voltage U_C on corner $\varphi_B - \alpha$. From here follows, that capacities of idling measured on separate phases at the transformer with asymmetrical magnetic system turn out equal:

$$P = P_{XA} + P_{XB} + P_{XC} = U_A I_{XA} \cos(\varphi_B - \alpha) + U_B I_{XB} \cos\varphi_B + U_C I_{XC} \cos(\varphi_B + \alpha), \quad (1)$$

Accordingly jet capacity will be equal:

$$Q = Q_{XA} + Q_{XB} + Q_{XC} = U_A I_{XA} \sin(\varphi_B - \alpha) + U_B I_{XB} \sin\varphi_B + U_C I_{XC} \sin(\varphi_B + \alpha), \quad (2)$$

Applying trigonometrically formulas for $\cos(\varphi_B+\alpha), \cos(\varphi_B-\alpha), \sin(\varphi_B-\alpha)$ land $\sin(\varphi_B+\alpha)$ and after some transformations we will receive:

$$\begin{aligned} P = U_A I_{XA} (\cos\varphi_B \cos\alpha + \sin\varphi_B \sin\alpha) + U_B I_{XB} \cos\varphi_B + \\ + U_C I_{XC} (\cos\varphi_B \cos\alpha - \sin\varphi_B \sin\alpha), \end{aligned} \quad (3)$$

$$\begin{aligned} Q = U_A I_{XA} (\sin\varphi_B \cos\alpha + \cos\varphi_B \sin\alpha) + U_B I_{XB} \sin\varphi_B + \\ + U_C I_{XC} (\sin\varphi_B \cos\alpha - \cos\varphi_B \sin\alpha), \end{aligned} \quad (4)$$

As $U_A = U_B = U_C = U$ and $I_{XB} = I_{XC}$ and having made some reductions we will receive:

$$P = U\left[I_{XB} + (I_{XA} + I_{XC})\cos\alpha\right]\cos\varphi_B, \quad (5)$$

$$Q = U\left[I_{XB} + (I_{XA} + I_{XC})\cos\alpha\right]\sin\varphi_B, \quad (6)$$

Concerning a phase B in currents in phases A and C are equal among themselves. Then

$$P = U\left[I_{XB} + I_{XA} \cdot 2\cos\alpha\right]\cos\varphi_B, \quad (7)$$

$$Q = U\left[I_{XB} + I_{XA} \cdot 2\cos\alpha\right]\sin\varphi_B. \tag{8}$$

It is necessary to notice that in modern three-phase transformers as the section yoke undertakes on (5 - 10) % of more section of cores, magnetic asymmetry of magnetic system happens it is insignificant. In that case it is possible to accept:

$$I_{XB} \approx I_{XA} \approx I_{XC} \approx I_0, \tag{9}$$

Considering equalities (9) in (7) and (8) we will receive:

$$P = UI_0\left(1 + 2\cos\alpha\right)\cos\varphi_B, \tag{10}$$

$$Q = UI_0\left(1 + 2\cos\alpha\right)\sin\varphi_B. \tag{11}$$

Apparently from (10) and (11) full active or jet capacity of the transformer it will be expressed not through $3UI_0\cos\varphi_B$, and will be in the form of $UI_0(1 + 2\cos\alpha)\cos\varphi_B$. It speaks, about that till now the factor 3 has been accepted without magnetic asymmetry of the transformer.

Apparently from (10) factor $(1 + 2\cos\alpha)$receives at$\alpha = 0$. However depending on increase α expression $(1+2\cos\alpha)$ decreases and accordingly the active capacity of the transformer consumed from a source decreases. By research it is established, that capacity of the transformer consumed from a source depends on its constructive sizes. If lengths of cores of the transformer to accept equal$h$, and distances between axes of cores d then the tangent of a corner of magnetic asymmetry will be in the form of [1]:

$$tg\alpha = \frac{\sqrt{3}}{3} \cdot \frac{1+2n}{3+2n} \;\; Or \;\; \cos\alpha = \sqrt{\frac{1}{1+b^2}}, \tag{12}$$

Where

$$n = \frac{2d}{h};\;\; b = \frac{\sqrt{3}}{3} \cdot \frac{1+2n}{3+2n}, \tag{13}$$

Depending on the constructive sizes shift of phases α from magnetic asymmetry can vary from 0^0 to 19^0.

Substituting (12) and (13) in (10) and after some transformations for P we get:

$$P = UI_0\left[1 + \frac{\sqrt{3}(3+2n)}{\sqrt{7+10n+4n^2}}\right]\cos\varphi_B, \tag{14}$$

At comparison of the equation (14) with equality $P = 3UI_0\cos\varphi_B$ we will receive:

$$1 + \frac{\sqrt{3}(3+2n)}{\sqrt{7+10n+4n^2}} \prec 3. \tag{15}$$

Solving last equation on n we will receive $|n| \succ 0,5$ and accordingly $d \succ 0,25h$.

Thus the formula (14) allows defining communication between capacities and the geometrical sizes of the transformer.

Using the formula (10) we find dependence between an error of capacity and magnetic asymmetry which registers in a kind:

$$\beta = 200 \cdot \frac{1-\cos\alpha}{3}\% = 67 \cdot (1 - \cos\alpha)\%. \tag{16}$$

Under the formula (16) we build dependences β on corner α which is presented on figure 2. Apparently from figure 2 with increase α the capacity error grows.

Substituting (13) in (16) active losses of capacity according to magnetic asymmetry and the geometrical sizes of the transformer are defined at an idling mode.

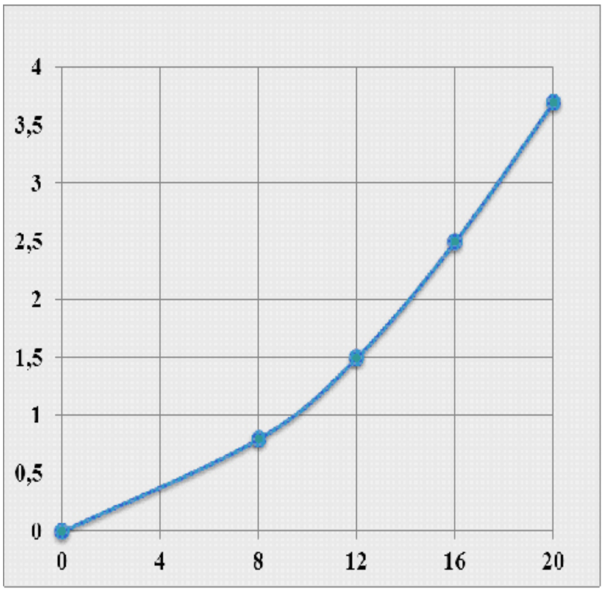

Figure 2. Dependence β **on** α

Dependence of losses of capacity from n is presented on figure 3.

Apparently, from the resulted characteristic (figure 3), with growth n power consumption of the transformer increases. If to accept that capacity of transformer $1MVt$ at $n = 0,1$ losses of capacity from magnetic asymmetry turn out equal $15,6kVt$ $(1,56\%)$. It means that at idling the transformer from a source instead of $1MVt$, can transfer on exit $984kVt$.

3. Conclusion

1. Despite quantitatively small value of losses caused by magnetic asymmetry of the individual transformer, modern electro power systems are characterised by operation of ten thousand transformers with various capacities, and it in turn demands the account of dependence of an error of capacity losses from magnetic asymmetry of magnetic conductivity transformers.

2. Dependences of an error of losses of capacity on magnetic asymmetry are received, and also analytical formulas for active and jet capacity of the transformer taking into account magnetic asymmetry of magnet conductivity are resulted. The received results can be applied at designing of substations of electropower systems.

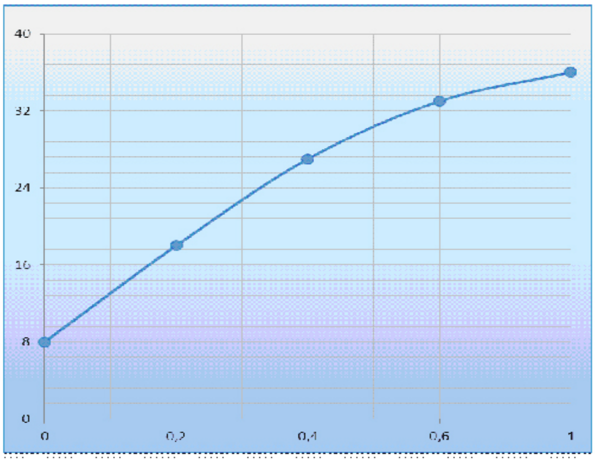

Figure 3. Dependence of losses of capacity from n in a mode of the single transformer course

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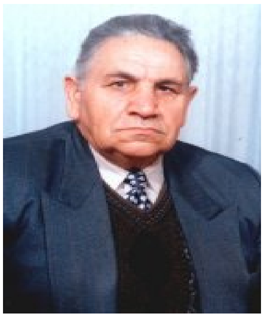

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