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PRACTICAL IMPLEMENTATION OF AC/DC MICROGRID WITH RENEWABLE SOURCES FOR ISOLATED AREA

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Abstract- As recently local networks with small power distributive systems to supply residential, office building and municipal, or farm units are in the progress. Such networks are preferable for island operation to supply with onsite generation internal loads but may also have power connection with the main electrical system. The technology used in such microgrids is small wind generators, PV solar panel systems, micro hydro units, micro gas turbines, fuel cells, CHP units and some others [1-8]. Until now a number of papers, describing advantages of rather novel idea to organize electrical power supply on regional level through creation of microgrid with traditional and renewable sources as well as developing smart properties of created microgid were presented. This paper is concentrated on study of a hybrid (combined) microgrid with AC and DC bus system with two main renewable sources of power as wind generator and PV-solar panel system.

Keywords: Microgrid, PV-Solar Panel, AC/DC Bus System, Battery Charging.

I. INTRODUCTION

One of the important advantages of the microgrid is the ability to give an opportunity to customers to make the intellectual decision in the way of using electrical power. If there is a need, microgrid could buy energy from the Grid, but at the time of increased price may be separated from a Grid and work in islanded mode. Microgrids provide not only energy source optimization but also power consumption. Good designed microgrid could withstand fault in the network not only by de-energization of a whole network or the part of it but also by selective switch-off of respective feeders.

II. COMBINED MICROGRID WITH PV-SOLAR UNITS TO COVER DEMANDS OF ISOLATED LOAD SYSTEM

To use microgrid effectively it is required to simulate and analyze the operation modes of combined AC/DC network. There are a few researches in this field [6-8]. Combined microgrid was chosen because of the development and deployment of renewable energy sources with dc output power and increasing number of end-users, which are using DC currents. Energy management, control and operation of a combined microgrid are rather difficult so efforts have been done to investigate some operating modes of it [3].

As we have seen from the schematic diagram of hybrid microgrid (Figure 1), there are two alternative sources of power – Wind energy generator (WG) and PV-solar energy unit. We study the case then latter is more powerful (450 kW) than WG (200 kW).

So let us concentrate on study of the main reliable source of free energy available right now from Solar Power which is being transduced to usable electrical energy by solar panels in form of DC energy.

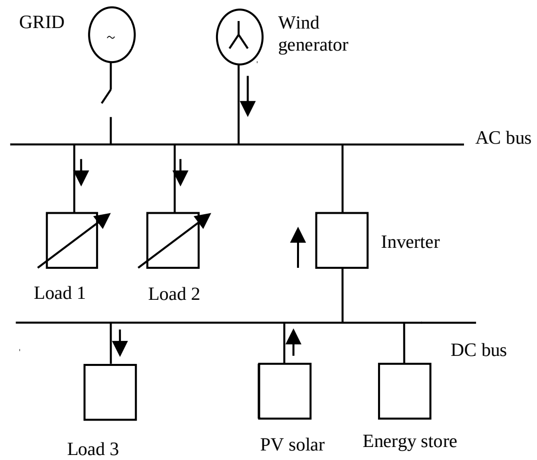

Figure 1. Schematic diagram of hybrid microgrid (Load1-static, Load2-lump load)

A. About Efficiency of Solar Panel

Every type of standard solar photovoltaic panel is rated for efficiency and these numbers are plastered all over industry literature [9].

They are as follow:

- Mono-Crystalline Silicon Cells 25% Efficient
- Poly-Crystalline Silicon Cells 23% Efficient
- CIGS Thin Film Cells 18% Efficient
- CdTe Thin Film Cells 16% Efficient
- Amorphous Silicon Thin Film 15% Efficient

At best, these numbers are an approximation, since every manufacturer publishes different values and rates their own products the best. There are also dozens of new, experimental solar panels being tested which show even higher efficiency numbers. So, the future looks like the efficiency of panels is going to keep rising. Of the five listed above, the three types of panels that are readily available are:

• Mono-Crystalline Silicon Cells 25% Efficient
• Poly-Crystalline Silicon Cells 23% Efficient
• Amorphous Silicon Thin Film 15% Efficient

The reality is that the average off-the-grid loads up being partly powered by Solar Energy and partly powered by a back-up generator. The *ongoing fuel expense of running this generator* is only one of several very large ongoing costs. The other very large ongoing cost of a solar system configured this way is the *recurring cost of replacing the batteries*. So we can see that the problems confronting a Solar Energy System aren't the efficiency of the panels or the efficiency of the inverter at all. They are the low electricity production during "off-peak" light conditions and the failure of the batteries to last as long as the manufacturer's say they should.

B. Solar Panel Problems

The Mono-Crystalline Silicon Solar Panels are recommended the most so let's see what they do. As stated before, this type of solar panel technology was developed by US Space Agency NASA to power satellites in orbit.

This graph shows the relationship between the light coming from the Sun and the sensitivity of the Crystalline Silicon panel to it. The wave length of the light is listed on the bottom of the graph in nanometers (nm). As a reference, visible light is between 400 and 700 nm. The yellow area represents the light spectrum in space and is listed as "Sunlight spectral (AM=0)." The AM=0 notation means "air mass = zero", which means the light outside the Earth's atmosphere. The graph shows that the spectral sensitivity of the Crystalline Silicon panel peaks between 900 and 1000 nm, and by the area under the curve, we can see that less than 20% of its electricity producing capability is in the visible spectrum of light between 400 and 700 nm.

The simple truth is, that this kind of solar panel is not even designed to operate on visible light! They really convert Infrared Radiation into electricity, since 80% of its sensitivity is between 700 and 1100 nm. Outside the atmosphere, this works great to power satellites.

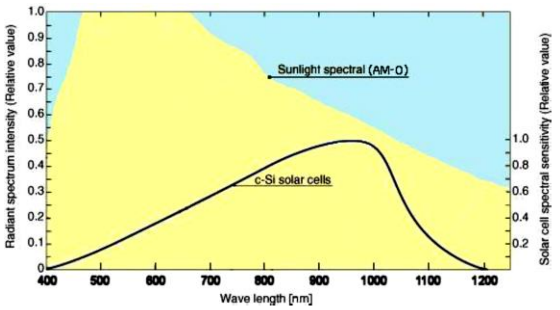

Figure 2. Spectral sensitivity of Crystalline Silicon panel at full Sunlight

Here is the graph of the Sunlight that gets through the atmosphere and the spectral sensitivity of the Crystalline Silicon panel. You can see that there are several areas of the spectrum that are not making it through to the Earth's surface and the largest obvious range is between 900 and 1000 nm, which is exactly what the Crystalline Silicon panels are designed to use! These "notches" represent the frequencies of Solar Radiation that are either reflected or absorbed by the atmosphere. And finally, here is the graph of how much of the Sunlight is available from behind a cloud. This is why the power drops off rapidly for this type of Solar Panel when the sun is blocked by clouds. Crystalline Silicon Solar Panels operate mostly on infrared radiation, which is represented as the wave lengths between 700 and 1100 nm. Only about 20% of their power comes from light in the visible spectrum. So, when a cloud goes by and blocks the heat from the Sun, these panels practically turn off.

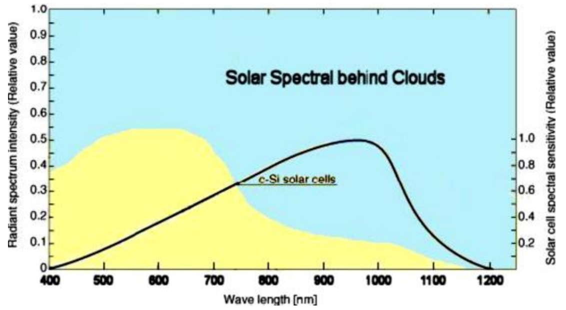

Figure 3. Spectral sensitivity of Amorphous Silicon panel at cloudy day

That is why they work great outside the atmosphere to power satellites and not so great down here on Earth. We can see now that the "25% efficiency" rating of this type of panel is really only in full sunlight conditions and they actually drop to about 5% efficiency or less in off-peak conditions.

Now let's look at the Spectral Sensitivity of the Amorphous Silicon Panel, shown as the RED LINE on this graph. As you can see, this type of panel is sensitive to frequencies all the way through the visible spectrum, which peaks between 550 (green) and 660 nm (red). This technology was developed for producing high output under low light conditions for pocket calculators and other portable electronic devices. They also have their highest sensitivity range right where the Sunlight is the brightest. That means even if the Sun is partially blocked by overcast conditions or a passing cloud, the Amorphous Silicon panel can still produce between 50% and 80% of its peak output! It is in these off-peak conditions where the Amorphous Silicon panels completely outperform the Crystalline Silicon panels. But if the Amorphous Silicon panels work better in real world conditions, why are they rated as having lower efficiency?

Here's why the efficiency ratings of the panels are all based on the idea that the total energy coming from the Sun hits the Earth at a rate of 1000 watts per square meter. That is a measurement of energy density in relationship to the area illuminated.

If we make a Crystalline Silicon Solar Panel that is exactly one square meter in size, it produces approximately 250 watts in full Sunlight, which is 25% of the 1000 watts of energy that is theoretically available. An Amorphous Silicon panel that is one square meter in size will produce about 150 watts in full Sunlight, which is about 15% of the 1000 watts available. So, that is where the efficiency numbers come from. They are a ratio between the area taken up by the panel and the electric power output during peak conditions.

So, a 1000 watt solar panel using the Crystalline Silicon technology will take up about 4 square meters of your roof and a 1000 watt solar panel using the Amorphous Silicon technology will take up about 6.6 square meters of your roof. The Crystalline Silicon panel is physically smaller, but only works well in direct Sunlight. The Amorphous Silicon panel is 60% larger, but works well in direct Sunlight and in a wide variety of indirect lighting conditions, as well.

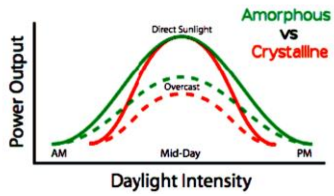

Figure 4. Amorphous silicon panel versus Monocrystalline

This graph illustrates the point fairly well. It shows that the Amorphous Silicon panel produces power longer when the sun is shining and produces more power all day when there are clouds.

Since it produces more power every day, no matter what the weather, that is just better performance! So, here is a situation where the criteria for rating efficiency is so screwy that the panels rated for "low efficiency" are obviously superior. They cost a little more, but they provide the best solar energy production your money can buy right now.

C. Problems of Storage Batteries

As we know, batteries for storing electrical energy at day-time to supply network at night-time are going to wear out at some point. All we are trying to do is make them last as long as they can. From a purely scientific and chemical point of view, this is way less true than most people believe. The fact is, most people who install a large solar power system in their home have no idea how to operate a large, battery based electricity storage system! What was common knowledge back in the 1920's and 30's has since faded from the public mind. The battery industry fully embraced "planned obsolescence" in the 1950's and ever since, has been happy to sell you a new battery whenever you needed one.

Regardless of what you have been led to believe, the Lead-Acid Battery is one of the most perfect and durable "chemical machines" ever devised. It is easily capable of being charged and discharged more than 5,000 cycles, which translates to being charged and discharged once a day for 15 years without special maintenance or replacement. And here is the punch line: batteries do not fail all by themselves. They are killed by the misuse and abuse of people who do not know how to use them properly! Premature battery failure is completely preventable, which means that the cost of battery replacement can easily be reduced to zero. It looks like the solar industry is using the wrong solar panel technology, it is using the wrong charge controller technology, it is using the wrong inverter systems, and it is blaming all of the subsequent problems on the batteries.

D. Battery Failure Scenario

- Insufficient power produced during off-peak solar conditions
- Batteries not fully charged at the end of the day
- Batteries need to be equalized on a regular basis
- Batteries eventually fail and need to be replaced

In spite of the fact that all of these problems are happening *to the batteries*, the batteries are *not the cause* of any of these problems.

The inability of the Crystalline Silicon solar panels to produce their rated power when there are clouds blocking the sun has already been discussed. So this is the beginning of the chain of events that leads to battery failure.

But lack of power coming from the panels is *not* the only reason the batteries are not fully charged at the end of the day! Technically, this is the job of the Charge Controller, as its name implies. A 12 volt Lead-Acid Battery charges according to a very specific set of specifications, the details of which are well known. This graph illustrates the process.

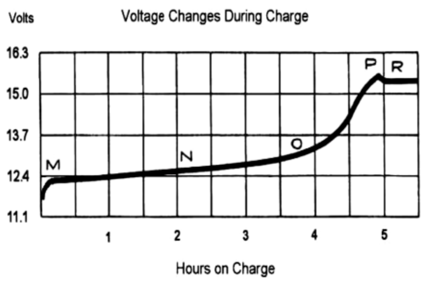

Figure 5. Charging process of a lead-acid battery

While most of the energy enters the battery along the slow ramp along line M-N-O, the charge process finishes when the voltage rises quickly to point P and then dips back slightly to point R. This is the electrical indicator that all of the chemical changes in the battery have finished and that the "charge process" is done. As the graph suggests, this voltage is a little above 15 volts! If the charge controller never lets the battery voltage rise to 15.2 volts, the charge process will never finish.

Anytime a battery is charged without letting the voltage rise to point P and then settles back to point R, a small amount of sulfating is left in the plates and this represents an incomplete charge cycle. This is the fundamental event that, when repeated over and over, eventually kills the battery. It is the charge controller`s fault. So, a charge controller that does not bring the battery to its natural "topping voltage" at the end of each charge cycle is the first step toward the battery failure.

Batteries that are charged to their topping voltage at the end of each charge cycle never need to be equalized because the individual cells in the batteries are always chemically and electrically equal at the end of the charge. By simply topping the battery each time, a huge amount of solar generated electricity isn't wasted and becomes available to power loads.

So, it should be fairly clear by now that the entire solar power system should be designed around providing the batteries what they need to last for their full, 5000 cycle lifetime. That is what makes a solar powered home, for example, operate most effectively, with extremely low maintenance and no extra costs.

E. Solar Energy Solution

It is possible to build and install a completely independent electricity supply for off-the-grid home using solar energy without the need for a back-up generator. This system includes the following components: Solar Panels that produce power under all of the possible conditions that your location normally experiences. For most of us, that includes sunny days, partly cloudy days, total overcast days, rainy days, and shorter days in the winter. The only solar panels that are readily available that can do this are the Amorphous Silicon thin film "low light" panels.

A Charge Controller that carefully brings the battery up to the topping voltage *without* over-charging it or causing heat or excessive off-gassing. Ideally, it would also protect the battery from dropping out of the charging mode when the system needs to power loads during the day.

The charge controller has to be designed around two imperatives. The first is recovering the maximum electricity from the solar panels and the second is providing the batteries with their ideal environment to enhance and lengthen their life-span. Our recommendation is the Tesla-Bedini solar charge controllers, designed by John Bedini.

III. MODELLING

So here are the components of a real, independent, solar power supply.

1. An Amorphous Silicon Solar Panel System
2. A battery topping Charge Controller (Tesla-Bedini).

This grouping of equipment can provide electricity to an off-the-grid home 24 hours a day, 365 days a year with extremely low maintenance and no ongoing costs for 15 years or longer. That is real, low cost, independent power.

Having in mind the considerations listed above we build 2-bus AC/DC power supply system this way, as shown in Figure 6. Example of microgrid modeling in ETAP 6 calculation program is presented in Figure 7 [10].

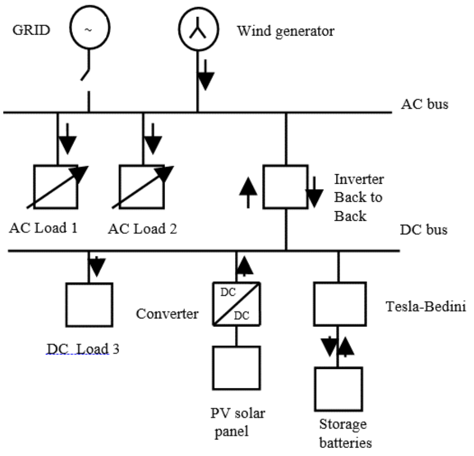

Figure 6. Schematic diagram of improved hybrid two bus power supply system

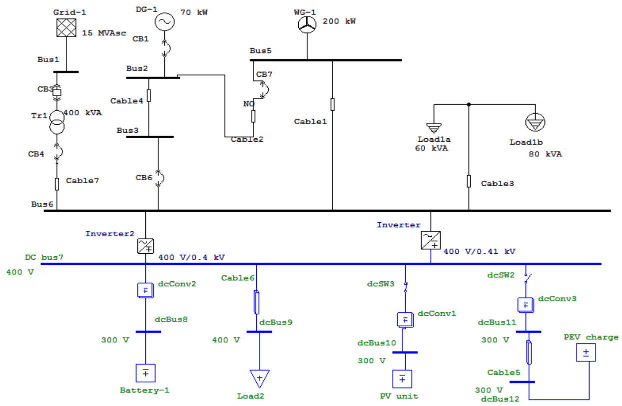

Figure 7. Modeling of combined 2-bus AC/DC microgrid system with ETAP 6 software

IV. MICROGRID UNDER STUDY IS IN ISLAND MODE

The connection to regional AC network is open. So AC bus has only one power source. It is the wind generator on base of 200 kW DFIG machine and is operating at wind speed 6 m/sec producing 94 kW of AC power. There are two AC loads – one is static load another is lump load. Both loads are with 200 kW nominal active power.

At Table 1 load flow, branch losses and voltage level on both busses as a function of load variation from 100% down to 30% with constant 94 kW power production from windmill are collected.

Table 1. Electrical characteristics of the regional AC network

Case	Load in %	AC bus voltage %	DC bus voltage %	Power from DC to AC in kW	Load 1 in AC bus kW	Load 2 in AC bus kW	Load 3 in DC bus kW	System losses kW
1	100	97.47	100	386.3	211/20	168/16	49.9	51.3
2	90	97.72		342.9	188/20	153/16		42.6
3	80	97.96		299.6	167/20	138/16		34.7
4	70	98.21		256.3	145/20	125/17		27.8
5	60	98.46		213.8	124/20	109/17		21.9
6	50	98.7		170.3	102/20	92/18		16.8
7	40	98.95		126.9	82/20	75/18		12.6
8	30	99.2		83.3	61/20	56/18		9.4

DC bus is fed by PV-solar panel system on the base of 150 W Amorphous Silicon Thin DC Film panels with total nominal power of 450 kW. There is a 50 kW load and battery storage which is connected to the DC bus through charge controller on base of Tesla-Bedini technology [11, 12]. This controller provides battery charging until the level slightly more than 15.2 V initiating the process of desulfatation in the battery [13].

Energy exchange between both bus systems is possible due to back to back inverter. To be convinced that such microgrid can afford to be a good power supply for their consumers on site we did vary AC load from 100% until 30% and results of calculations put in a Table 1. According data collected in Table 1, voltage level on DC bus is constant, and voltage level on AC bus is slightly changed, but the differences in 5% band of IEC Standards. Maximum power loss in AC part of the system is 51 kW which is about 8% of total consumed power in AC network. To cut a power loss check the parameters of used power cables is proposed. If we use a half of nominal AC power at both Load1 and Load2 (170 kW total AC bus load) it is possible to keep microgrid alive rather a long period of day time without being connected to grid or turning on any back-up systems with conventional fuel.

V. CONCLUSION

1. Carefully projected Combined AC/DC microgrid could be reliably operated in island mode without any backup sources (diesel) using conventional primary fuel.
2. In practical purposes it is recommended to use Amorphous Silicon Thin DC Film PV-solar panels, because they produce more electrical energy within the year comparing with mono-crystalline silicon solar panels.
3. To provide long life to energy storage batteries it is suggested to use Tesla-Bedini charge controllers.

APPENDIX

Situation with Solar Power Radiation in Azerbaijan

Radiation division of Azerbaijan Academy of Science has conducted researches devoted to solar potential of country. Measurements were done throughout the country for silicon based photovoltaic generators. Results can be observed from Table 2.

Table 2. Annual electrical energy production (kWh/m^2)

Climate zone	Geographical meridian	Photovoltaic module					
		I	II	III	IV	V	VI
I. The Grand Caucasus area							
South slope:							
1. Shaki-Zagatala area	41.3	193.9	226.8	199.2	197.6	220.2	221.1
2. Shaki-Shamakha area	41.0	202.4	239.3	208.8	207.5	232.0	232.5
North-east slope:							
3. Gouba-Khachmas area	41.3	205.9	240.2	211.7	209.6	231.6	234.1
4. Gilazi-Dyubrar area	40.9	204.0	239.1	209.8	207.9	231.0	232.5
II. Small Caucasus area							
5. Northern part	40.5	205.5	247.3	214.8	209.1	239.1	240.7
6. Southern part	40.0	209.4	250.3	218.8	215.5	242.1	244.4
III. Nakhchivan area	39.2	245.4	291.5	255.8	253.5	281.9	284.4
IV. Lenkoran area	38.8	210.7	255.2	221.0	220.5	244.2	247.3
V. Central desert area							
7. Koura-Araz area	40.0	230.3	275.3	240.6	237.0	264.3	268.8
8. Absheron area	40.3	208.7	253.0	219.3	215.9	240.4	246.5

REFERENCES

[1] N.R. Rahmanov, N.M. Tabatabaei, K.M. Dursun, O.Z. Kerimov, "Combined AC-DC Microgrids: Case Study-Network Development and Simulation", 8th International Conference on Technical and Physical Problems of Power Engineering (ICTPE-2012), Fredrikstad, Norway, pp. 8-12, 5-7 September 2012.

[2] A.M. Hashimov, N.R. Rahmanov, O.Z. Kerimov, "Integrated Hybrid Microgrid - The Cell of Future Distribution Network", 9th International Conference on Technical and Physical Problems of Power Engineering (ICTPE-2013), Istanbul, Turkey, pp. 1-5, 9-11 September 2013.

[3] N.R. Rahmanov, A.M. Hashimov, O.Z. Kerimov, "Effect of Combined Wind and Diesel Generation on Power System Operation", Renewable Energy World Conference, Milan, Italy.

[4] R. Noroozian, M. Abedi, G. Gharehpetian, "Combined Operation of AC and DC Distribution System with Distributed Generation Units", Journal of Electrical Engineering, Vol. 61, No. 4, pp. 193-204, 2010.

[5] R.H. Lasseter, P. Paigi, "Microgrid: A Conceptual Solution", IEEE 35th PESC, Vol. 6, pp. 4285-4290, June 2004.

[6] R.H. Lasseter, "Microgrids", IEEE Power Eng. Soc. Winter Meeting, Vol. 1, pp. 305-308, January 2002.

[7] P. Wang, X. Liu, Ch. Jin, P. Loh, "A Hybrid AC/DC Microgrid Architecture, Operation and Control", IEEE Power and Energy Society Meeting, San Diego, CA, USA, pp. 1-8, 24-29 July 2011.

[8] X. Liu, "A Hybrid AC/DC Microgrid and its Coordination Control", IEEE Transactions on Smart Grid, Vol. 2, Issue 2, pp. 278-286, June 2011.

[9] P. Lindemann, "Solar Secrets", A&P Electronic Media Liberty Lake, WA 99019, 2014.

[10] ETAP 6.0 Software, Operation Technology.

[11] J. Bedini, "Device and Method of a Back EMF Permanent Electromagnetic Motor Generator", US Patent # 6,392,370 B1, May 21, 2002.

[12] J. Bedini, "Device and Method for Utilizing a Monopole Motor to Create Back-EMF to Charge Batteries", US Patent # 6,545,444, ~ US Cl. 318/798, April 8, 2003.
[13] T.E. Bearden, "Bedini's Method for Forming Negative Resistors in Batteries", J. New Energy, Vol. 5, No. 1, pp. 24-38, Summer 2000.

BIOGRAPHIES

Nariman R. Rahmanov received the M.Sc. and Ph.D. degrees from Azerbaijan State Oil and Chemistry Institute (Baku, Azerbaijan) in 1960 and 1968, respectively. He received the Doctor of Technical Sciences in Power Engineering from Novosibirsk Electro technical Institute, Russia in 1990. He is a Professor since 1990 and Director of Azerbaijan Scientific Research Institute of Energetic and Energy Design (Baku, Azerbaijan) from 2007 up to 2009, and Deputy Director of the same institute and SPII from 2009 up to present. He is Director of Azerbaijan-Norway Center of Cleaner Production and Energy Efficiency (CPEE Center). He is the member of IEEE, Academician of International Eco-Energy Academy (Baku, Azerbaijan), Co-Chairman of International Conference on "Technical and Physical Problems of Electrical Engineering" (ICTPE), member of Editorial Boards of International Journal on "Technical and Physical Problems of Engineering" (IJTPE) and Journal of Power Engineering Problems. His publications are more than 200 articles and patents, and also 3 monographs. His research areas are power systems operation and control, distributed systems, alternative energy sources. His publications are more than 210 articles and patents, and also 3 monographs.

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Sabina T. Ahmedova was born in Baku, Azerbaijan, in 1972. In 1995, she has received M.Sc. degree from Azerbaijan State Oil Academy, Baku, Azerbaijan. Her Ph.D. work was devoted to optimization and forecasting of modes of power systems using models of an artificial intellect. She joined to Azerbaijan Research Institute of Energetics and Energy Design, Baku, Azerbaijan in 1996 and now her position is leading engineer.

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