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HYBRID DISTRIBUTED GENERATION SYSTEMS CONSTRUCTION WITH RENEWABLE ENERGY SOURCES FOR REMOTE CONSUMERS POWER SUPPLY

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Abstract- This article considers the stages of the problem of choosing renewable energy sources (RES) and their use in the power system for remote rural areas and isolated rural-type settlements. In order to cover the demand for electricity for some regions of Azerbaijan the results of studies for renewable energy sources potential are presented. To create the system, the use of renewable energy sources, modern technologies in the field of generation and distribution of electricity, Smart consumption systems are proposed. In this study, to assess the potential of the available types of renewable energy sources, data from measurements of solar radiation, ambient temperature, wind speed and other geographic and climatic parameters were used. Research on the potential of renewable energy sources has been carried out, the geographic and technical potential of solar and wind energy for the selected regions has been determined. The technical characteristics of power generation by solar PV installations and wind turbines, planned for placement in the studied regions, have been determined.

Calculations of the flow distribution in a distributed generation (DG) system with a hybrid combination of renewable energy sources (solar PV and wind power plants), the choice of a combination and operating mode of a diesel generator and batteries - electric energy storage are carried out.

Keywords: Renewable Energy Sources, Solar and Wind Potential, Rural Development**.**

1. INTRODUCTION

Currently, one of the most important areas of the power industry transformation is the development of RG technology using renewable energy sources to cover demand in remote areas [1, 2, 3].

Today, according to the RG system, power supply systems have been built for many rural settlements remote from the central energy system, municipalities and districts with small enterprises, as well as settlements, the power supply of which is carried out using local traditional sources [4, 5, 6].

Over the past several decades, the share of renewable energy sources in the electric power systems has grown significantly. This is associated with a significant reduction in natural fuel resources, and with the growth of generation from natural fuels, as well as the need to protect the environment. The growth in the generation of electrical energy due to renewable energy sources necessitates further improvement of the structure of the RG, the creation of new approaches in the management of microsystem modes, using the resources of small rivers, thermal waters, the combined use of renewable energy sources [7, 8, 9]. In situations where most of the electricity in the power system is generated in thermal power plants, transferring little power to remote areas is unreliable and expensive. In addition, it is difficult to maintain the quality of electricity for rural consumers when powered from the electric grid from long low voltage lines, which also negatively affects the socio-economic development of rural areas.

In recent years, rural areas and isolated remote settlements have become important for energy transformation. These areas are not only significant as places for the use of renewable energy sources, but also have great potential for the joint implementation of the principles of energy efficiency and energy conservation, optimal combined use of various types of renewable energy sources, which also supports sustainable development of rural areas [8, 10]. The use of RES in remote rural areas will significantly improve the employment of the population. To improve the economic benefits from the development of renewable energy sources, renewable energy needs to be well adapted to local conditions. Currently, there is no sufficient global experience in the development of remote areas using RES, there is no realistic assessment of the potential benefits from the development of RES for remote locations located in different geographic and climatic conditions.

An analysis of observational data on the variability of weather parameters (solar radiation, wind speed) on the one hand, on the other hand, the presence of other types of renewable energy resources (thermal waters, small rivers, biological resources, etc.) in the regions of Azerbaijan shows that it is most beneficial to use solar energy for them. The solar energy resource significantly exceeds the wind energy resource.

Power generation by solar PV power plants and wind turbines is of an intermittent and random nature, therefore, backup sources - a diesel generator and a battery system for storing electrical energy are connected to the system [12, 13, 14].

Combined power generation control PV-wind-diesel stations in the scheme of the distributed generation RG system for autonomous power supply of remote are as consists in optimal coverage of consumption during the day. The fulfillment of the conditions for the balance of demand and coverage, reliability and stability is one of the most important advantages of the considered hybrid RG system. A balanced system can ensure stable generation by sources and minimize the dependence of their productivity on seasonal changes, in addition, it will allow determining a schedule for the priority use of existing renewable energy sources in different periods of time [15, 16]. In addition, with the simultaneous use of energy storage devices in the RG scheme with RES, the cost of investments will be significantly reduced [16]. Currently, among the existing types of renewable energy sources in the world, solar PV and wind power plants are the most widely developed, which is largely provided by energy storage devices. Maintaining the continuity of operation of the RG with integrated solar PV sources and wind turbines is an important task of the system in its isolated operation. Thus, the requirement for the integrated operation of solar PV and wind power plants with an electric storage system corresponds to the creation of conditions for the continuous functioning of the system.

2. ASSESMENT OF SOLAR AND WIND ENERGY POTENTIAL

This work covers research on the potential of solar and wind energy for a number of regions of Azerbaijan. The geographical point of the center of the corresponding region was considered as the geographical coordinate in which the hourly changes in the density of solar radiation, wind speed and other additional parameters characterizing these values were recorded. Daily hourly records of measured values are presented for a period of 20 years (1998-2018).

2.1. The energy potential of Solar energy resources:

It is known that the average annual (24 hours) power density of solar radiation is usually in the range of 100-300 W / m^2 (in the horizontal plane) [17].

At the same time, for the construction of a solar station with an average power generation of 100 MW, an area of 3 to 10 km^2 is required (this is approximately one times more than the area occupied by a traditional thermal power plant). However, the total average power available on the Earth's surface in the form of solar radiation exceeds the total power supply in the world by 1,500 times [4].

It should be considered that the power of solar radiation falling on the roof of buildings is in many cases comparable to the average power consumption inside the building. Many other factors, including geographic and economic ones, play a significant role in determining the real energy potential of solar radiation per unit area of the surface of the area under study. It is necessary to take into account the correspondence between the demand for electricity and the availability of the real volume of solar radiation, on the basis of which it is planned to cover part or all of the given demand.

The Tables 1 and 2 show the parameters of solar radiation (average monthly values) for two selected regions.

Table 1. Average monthly values and annual amount of solar radiation

Month	*GHI* kWh/m^2	*DNI* kWh/m^2	*DIF* kWh/m^2	D2G	*Temp* ºC
Jan	64.0	96.4	26.9	0.420	-4.2
Feb	79.4	94.3	35.0	0.441	-2.6
Mar	110.7	97.0	54.9	0.496	1.9
Apr	124.5	82.0	70.6	0.567	7.1
May	151.7	105.2	80.0	0.528	11.7
Jun	179.3	139.2	80.5	0.449	15.5
Jul	187.7	143.8	84.2	0.449	18.3
Aug	172.8	144.2	73.8	0.427	18.6
Sep	121.0	107.4	55.3	0.457	14.4
Oct	92.9	96.9	43.3	0.466	9.1
Nov	68.2	96.6	28.1	0.412	2.6
Dec	57.2	90.2	24.9	0.436	-2.5
Yearly	1409.4	1291.1	657.7	0.467	7.5

Table 2. Average daily values and annual amount of solar radiation in selected region

Month	*GHI* kWh/m^2	*DHI* kWh/m^2	*DF* kWh/m^2	D2G	*Temp* ºC	*WS* m/s
Jan	58.6	81.2	25.4	0.433	0.0	2.0
Feb	74.2	81.0	33.7	0.454	1.6	2.2
Mar	115.0	101.3	52.9	0.460	6.1	2.2
Apr	137.7	98.7	69.9	0.503	11.1	2.2
May	185.4	143.6	80.3	0.433	15.9	2.3
Jun	213.6	180.2	79.8	0.373	20.3	2.6
Jul	211.9	168.9	86.8	0.409	23.3	2.7
Aug	187.9	157.0	76.7	0.408	23.4	2.6
Sep	137.5	123.4	57.7	0.420	18.4	2.3
Oct	94.0	93.1	43.2	0.460	12.7	1.9
Nov	62.8	78.9	28.0	0.446	6.4	1.8
Dec	52.4	75.9	23.6	0.450	1.3	1.9
Yearly	1531.0	1383.2	657.2	0.429	11.7	2.3

The calculations of hourly power generation during the month for some regions were also carried out. Tables 3 and 4 show the corresponding calculated data on the hourly specific power and the average for the territories of the regions, leading to these zones. The values of the sum of average monthly radiation and the corresponding value of the sums of monthly power generation are equal to 1710 kWh/m^2 and 1440 kWh/month and, respectively, for other regions - 1600 kWh/m^2, 1350 kWh/month.

Table 3. The value of the average hourly and average daily electricity production (Solar PV [w×hrs/kWp]) for region 1

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0-1	-	-	-	-	-	-	-	-	-	-	-	-
1-2	-	-	-	-	-	-	-	-	-	-	-	-
2-3	-	-	-	-	-	-	-	-	-	-	-	-
3-4	-	-	-	-	-	-	-	-	-	-	-	-
4-5	-	-	-	-	-	-	-	-	-	-	-	-
5-6	-	-	-	-	0.8	2.4	0.6	-	-	-	-	-
6-7	-	-	-	6.6	30.8	39.2	30.9	11.0	0.9	-	-	-
7-8	-	0.9	22.4	77.3	116.7	125.7	105.5	91.9	70.8	29.3	1.2	-
8-9	24.7	78.5	144.5	208.5	256.2	270.8	242.1	236.9	224.1	196.9	107.5	29.9
9-10	203.3	259.0	292.2	341.8	384.2	405.1	378.8	382.4	359.8	339.6	308.8	200.5
10-11	371.0	406.5	415.0	442.7	475.3	494.5	490.3	500.4	468.5	457.5	430.5	383.1
11-12	474.2	531.9	529.1	501.9	519.2	549.6	565.7	574.5	536.2	546.3	510.3	468.0
12-13	522.5	581.7	572.5	507.4	506.9	559.6	586.2	612.0	533.8	513.8	519.5	493.4
13-14	497.7	533.8	505.2	456.6	449.5	524.4	566.8	590.3	491.9	446.2	481.3	467.4
14-15	439.6	466.6	443.8	386.9	370.9	470.4	513.2	535.2	422.0	365.1	401.9	409.2
15-16	356.7	385.2	361.0	312.8	299.5	394.5	437.2	445.7	335.1	277.3	299.6	318.4
16-17	151.1	274.0	262.9	230.7	225.1	301.4	332.4	331.0	232.4	175.0	78.0	28.0
17-18	6.5	65.6	143.0	133.8	143.7	192.0	207.6	192.8	116.7	18.0	2.1	1.5
18-19	-	1.6	12.4	41.7	63.7	84.5	91.2	68.2	11.1	0.1	-	-
19-20	-	-	-	1.1	10.6	23.3	22.2	4.8	-	-	-	-
20-21	-	-	-	-	-	0.1	0.1	-	-	-	-	-
21-22	-	-	-	-	-	-	-	-	-	-	-	-
22-23	-	-	-	-	-	-	-	-	-	-	-	-
23-24	-	-	-	-	-	-	-	-	-	-	-	-
Sum	3047.3	3585.4	3704.0	3649.7	3853.1	4437.5	4570.7	4577.0	3803.3	3365.1	3140.7	2799.3

Table 4. The value of the average hourly and average daily electricity production (Solar PV [w×hrs/kWp]) for region 2

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0-1	-	-	-	-	-	-	-	-	-	-	-	-
1-2	-	-	-	-	-	-	-	-	-	-	-	-
2-3	-	-	-	-	-	-	-	-	-	-	-	-
3-4	-	-	-	-	-	-	-	-	-	-	-	-
4-5	-	-	-	-	-	-	-	-	-	-	-	-
5-6	-	-	-	-	0.8	2.0	0.5	-	-	-	-	-
6-7	-	-	-	6.1	28.4	37.2	28.9	10.4	0.9	-	-	-
7-8	-	0.7	22.1	71.2	113.6	126.0	104.3	89.6	66.9	26.6	1.0	-
8-9	21.3	73.9	137.8	193.3	252.9	274.6	241.9	230.1	211.0	176.9	94.0	25.5
9-10	192.0	230.4	277.6	323.0	389.3	420.0	390.8	376.8	357.2	311.5	273.8	210.6
10-11	348.5	268.3	415.7	442.7	511.7	545.8	521.6	510.9	484.1	431.5	395.4	366.6
11-12	454.9	493.3	544.4	532.7	604.7	642.9	619.4	609.7	586.2	546.0	475.6	450.7
12-13	505.0	558.2	599.4	569.6	643.2	683.9	665.6	665.4	627.8	543.3	500.0	487.1
13-14	495.2	531.1	558.1	554.5	620.9	673.2	659.0	664.6	612.1	501.0	475.0	471.2
14-15	437.4	469.5	503.0	493.5	554.0	617.2	616.0	609.9	550.7	429.8	406.0	334.6
15-16	138.3	395.0	416.1	396.4	436.7	520.2	521.3	516.5	448.2	274.5	55.1	51.5
16-17	38.9	60.0	251.5	280.7	307.7	381.2	389.3	375.7	300.4	54.8	31.6	27.6
17-18	6.0	29.3	50.5	140.1	175.1	224.2	235.7	213.3	53.7	17.7	2.0	1.3
18-19	-	0.5	11.5	30.8	64.7	88.6	96.0	60.0	12.0	-	-	-
19-20	-	-	-	0.9	9.6	20.8	20.7	4.2	-	-	-	-
20-21	-	-	-	-	-	-	-	-	-	-	-	-
21-22	-	-	-	-	-	-	-	-	-	-	-	-
22-23	-	-	-	-	-	-	-	-	-	-	-	-
23-24	-	-	-	-	-	-	-	-	-	-	-	-
Sum	2637.5	3210.0	3787.8	4035.3	4713.3	5258.0	5111.0	4937.1	4306.2	3314.5	2709.4	2426.6

2.2. Wind Energy Potential

To assess the potential of wind energy in the considered regions, stochastic characteristics of the variability of wind speeds during the day, week, month and year were investigated.

The table shows data on average monthly values of wind speeds in the indicated areas for the period 1998-2018.

In principle, wind speeds are equally low in all areas. But nevertheless, for the indicated speeds, the most effective can be considered wind turbines with a vertical axis, operating almost continuously throughout the year. The selection of wind turbines for operation in low potential wind conditions requires more detailed additional research.

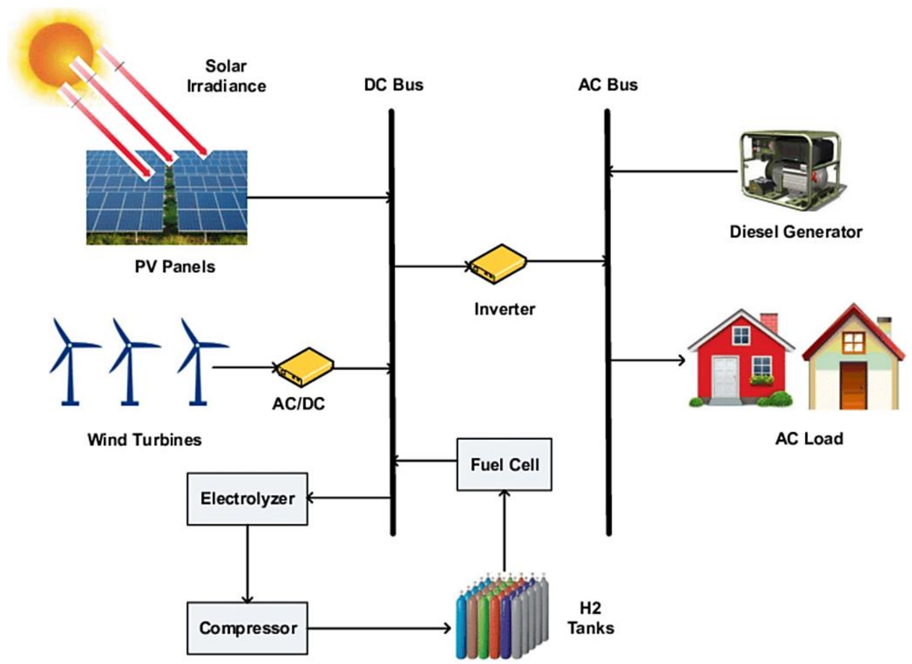

Figure 1. General view of the Hybrid Micro-Grid for remote areas [12]

Table 5. Structure and parameters of the DG system with a hybrid composition of renewable sources connected by two bus AC-DC circuit

AC subsystem with RES and AC loads					DC subsystem with RES and DC loads			
Wind Stations general purpose	WT at private homes	Diesel Generator	Lump Load	Load 1	Solar PV station	Accumulator batteries	PEV	Load 2
90 kW	50 kW	100 kW	150 kW	70 kW	300 kW	60 km (120 kwh)	5 km	70 km

3. TYPICAL STRUCTURE OF AN AUTONOMOUS MICRO-ENERGY SYSTEM WITH RES FOR REMOTE RURAL SETTLEMENTS AND MUNICIPALITIES

Currently, the share of RES using the potential of local renewables has significantly increased in the DG systems created to supply power to hard-to-reach remote places. Various approaches have been proposed for the design of individual microsystems of power supply for consumers in remote locations, which differ from the nature of the projected power supply facility and the composition of renewable sources used in power supply scheme [18, 19].

A remote power system using renewable energy sources can be used to supply electrical energy to a wide range of consumers:

- special use: supplying water pump / refrigerator [20];
- power supply of the network of houses: electrical systems of individual houses, buildings, consumer centers [21];
- power systems of individual municipal areas: power systems of the entire municipal area may contain traditional sources, renewable technologies and energy storage technologies [22].

Further development of the technology of distributed generation microsystems with integrated renewable sources made it possible to create modern hybrid wind-solar-diesel-battery microsystems for power supply of remote rural and municipal areas [23, 24].

Hybrid municipal systems:
- Wind / Solar / Diesel systems
- Central power facilities which distribute AC power between houses
- a system formed from solar and wind stations, batteries for storing electrical energy, as well as traditional sources
- the use of the battery, when this is appropriate for storing renewable energy at night or for a short time based on the possibility, but renewable energy.
- a generator used as a backup or secondary power source.

Maximizing the potential of local renewable resources is considered an important requirement for the formed micro-grid structure for remote locations. Described system is presented at the Figure 1.

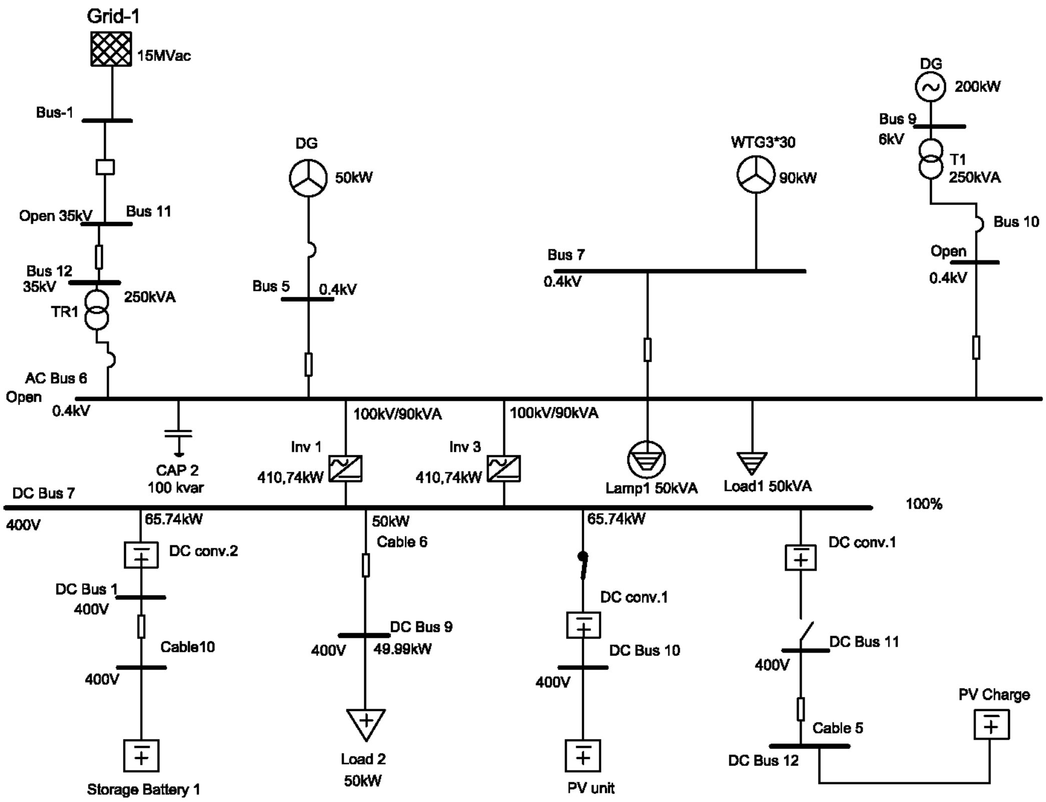

Figure 2. General view of the Hybrid Micro-Grid for remote areas [1]

4. SIMULATION OF POWER FLOWS IN A MICROGRID WITH WIND AND SOLAR STATIONS, DIESEL STATION AND ACCUMULATORS

To assess the technical and economic scheme of a hybrid micro-grid, an analysis of the flow distribution in the system is carried out for different periods of time. The power generation capacities of solar PV and wind power plants are calculated from the data of temporal changes in solar radiation and wind speed obtained from measurements carried out in individual areas.

The power generation PV and WT by power plants are stochastic and intermittent variables, which during operation in some random periods of time may exceed the value of the power consumed by the load and the value of the maximum charging power of the battery storage system of electrical energy. In such cases, to ensure the stability of the functioning of the distributed generation microsystem, the excess power generated by PV and WT power plants is "thrown away" by limiting generation from renewable sources.

Based on the data of hourly average values of PV power generation by stations and hourly average values of power generation by wind farms, calculations of the flow distribution mode in the AC-DC scheme of the DG system for rural settlements located in the selected regions were carried out. To compare the distribution of power flows in AC and DC networks, the cases were considered for the following time periods (days of months):

1. maximum radiation and minimum wind speeds
2. maximum wind speed and minimum radiation
3. various combinations of solar radiation and wind speeds in a time interval of one month throughout the year.

The Diagram of the Micro-Grid Power Flows Simulation study is presented below at the Figure 2.

5. CONCLUSION

The world experience of completed projects shows that autonomous electrification systems based on renewable energy sources are the most acceptable in comparison with systems with traditional sources. However, it should be noted that MG isolated systems require several technical and organizational problems to be solved. In fact, from each implemented project of the MG RES system, some recommendations can be drawn when designing similar projects in similar geographic locations.

One of the important goals of the conducted research is the efficient use of the potential of renewable resources to cover the needs in electric rural areas. Increasing the accuracy of determining the synchronous temporal variability of power generation by solar PV modules and wind power generation will allow creating a model of a priority combination of PV and WT generation power values in the current periods of load power changes.

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BIOGRAPHIES

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