Determination of technical and economic efficiency of microgrid based on renewable energy sources

Jurabek Izzatillaev[1*], Pavel Navitski[2], Sirojiddin Khushiev[1], Abdushoxid Mamadjanov[3], Azizbek Akrombaev[4]

[1]Department of Power Supply and Renewable Energy Sources, Tashkent Institute of Irrigation and Agricultural Mechanization Engineers, 100000 Tashkent, Uzbekistan
[2]Department of Engineering, Oral Roberts University, Tulsa, 74171 OK, USA
[31]Department of Power Engineering, Namangan Engineering - Building Institute, Turakurgan, Uzbekistan
[4]Department of Economic, Tashkent State University of Economics, Toshkent, Uzbekistan

Corresponding author: izzatillaev.jurabek@gmail.com

Abstract. This article proposes a modern feeder-type microgrid, which is considered energy-efficient and environmentally friendly, and the prospects for its development, the planned work to increase the share of renewable energy sources in the electricity balance in Uzbekistan, as well as a method for determining the feasibility of creating microgrids based on renewable energy sources. In the calculation work, a 10 kV SHFK feeder was selected as a microgrid, which is located in the Uychi district (Namangan region).

INTRODUCTION

Particular attention is paid to stabilizing the ecological balance in the world and saving various hydrocarbon fuels, the use of non-conventional and renewable energy sources, expanding the range of quality and uninterrupted supply of electricity to consumers. In developed countries today, "…the modern energy sector must resolve three key, but often contradictory, tasks: ensuring security, raising energy efficiency and working for a clean environment. Solutions to these problems can be found by developing contemporary intelligent micro-networks or microgrid (MG)s, which will enable compatibility of renewable and traditional sources and also the interests of consumers and producers." [1]. In this regard, special attention is paid, in particular, to the development of consumer power supply systems and the creation of micro-electrical systems without harming the environment. Globally, the use of MGs is growing exponentially with time due to their intelligent characteristics and significant impacts on the efficiency and reliability of grid provided power [2-3].

During the last 2008-2018, the volume of electricity generation in the country amounted to about 10.2 billion kWh per hour. In 2019, 62.0 billion kWh of electricity was generated and the growth rate was 102.3%.

According to the forecast, in the period up to 2030, the annual growth of electricity demand in the Republic will be 6-7%. By 2030, the republic's consumption will reach 120.8 billion sums kWh (1.9 times more than in 2018). At the same time, the population's demand for electricity is 21.9 billion sums kWh, the demand for electricity in the economic sector - 85.0 billion kWh is expected.

By 2030, per capita electricity consumption is expected to increase to 2,665 kWh per year and to increase by 71.4% compared to 1,903 kWh in 2018.

Taking into account the best international practices and modern trends in world electricity development, the Concept of electricity supply of the Republic of Uzbekistan for 2020-2030 has been developed in order to meet the growing needs of the Republic of Uzbekistan and ensure more balanced development of the electricity sector. According to him, the capacity of new power plants to be commissioned in the country by 2030 (in terms of years) in order to generate electricity on the basis of renewable energy sources (RES). In order to achieve the development of renewable energy, the target parameters of the annual capacity of RES, which is planned to build 3 GW of wind and 5 GW of PVP in 2020-2030.

One aspect of the development of intelligent power systems is the new MG concept. According to the United States' Department of Energy defines an MG as a collection of loads and distributed energy resources (DERs) that are interconnected together under predefined standards to form a single controllable structure that can be worked while linked with the main grid or isolated from it [4-5].

When the state of the main power transmission grid (MPTG) is normalized, the MG is automatically synchronized in the same uninterrupted manner and reconnected to the MPTG without interruptions in the power supply. That is, in normal mode, the MG operates as part of the main power grid and switches to stand-alone mode for some time during the troubleshooting period of the main power grid. Conversely, MG operates "autonomously" if there are problems with the ability to connect to the central power grid (technically or economically or in the normative and technical documents on the connection). According to CIGRE´ WG6.22 definition, microgrids are comprised of (distributed energy resource) DERs and loads that can be operated in a coordinated and controlled system either while connected to the main grid, i.e., grid-connected mode, or while islanded, i.e., off-grid mode [6]. Typically, many electricity grids of remote communities are operating "off-grid." In other words, they are not connected to the main grid.

The pace of practical use of MG s in the world has increased dramatically in recent years [7]. According to a new report by analytics firm Navigant Research, for comparison, the 2019 MG market features 3,480.5 MW, totaling a $8.1 billion market. By 2028, those numbers grow to 19,888.8 MW and $39.4 billion, respectively, in annual implementation spending.

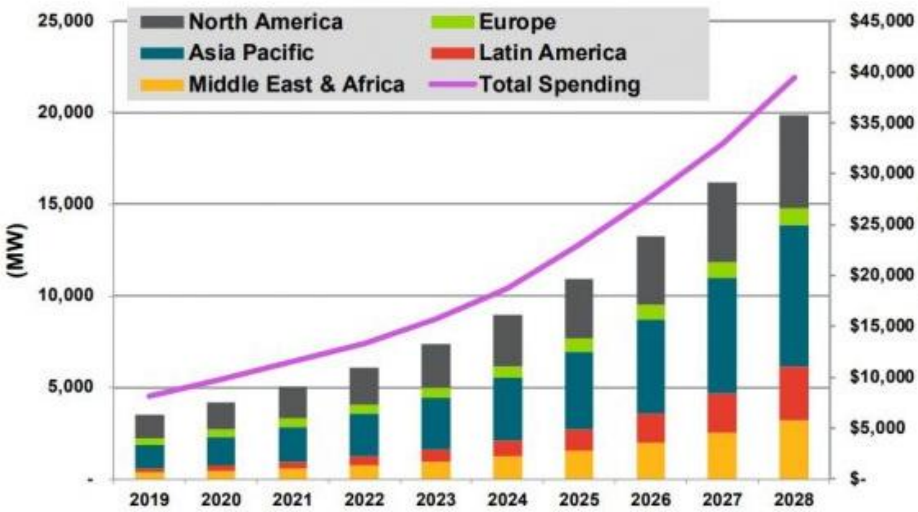

FIGURE 1. Annual total MG power capacity.and implementation spending by region world markets (2019-2028)

There are three different advantages associated with MGs: technical, economic, and environmental. [8-9] cited a number of advantages, such as supporting consumers in a technically isolated area, increasing energy efficiency, lack of organic linkages with MPTGi, and reducing the number of power outages. Cost-effectiveness and reduction of environmental pollution and losses in the power grid, minimization of the cost of power outages for the customer, the cost of fuel and additional services, etc. and the environmental benefits of MGs [10].

Photovoltaic cells (PV) and wind power generation are the most popular of the energy sources that can be integrated into the main network in the form of DGs or MGs. Indeed, MGs consist of a methodical organization of such DG systems [11-16]. The paper [17] presents design and planning methods for the development of renewable energy microgrids in remote systems using the sustainability philosophy as a guiding framework. There are also some publications which deal with economic potential and technological capabilities of microgrids [18-19].

METHODS

One of the most effective ways to increase the reliability of power supply in MG is to use the existing RES in the regions and optimize the operating modes of the main devices.

The main indicators that determine the creation of RES-based MG are capital expenditures. Basically, depending on this indicator, the question of whether or not to build MG s is determined. Due to the use of existing 0.4 kV overhead power lines for the creation of autonomous MGs in the region, the calculation work will be carried out only for the selection of power plants. There are several ways to determine capital expenditures.

Taking into account the depreciation of money (inflation), capital expenditures are calculated as follows [20]:

$$K_t = \frac{K_{t-1}}{(1-\frac{\varepsilon_{inf}}{100})^{t-t_{b.constr}}}; \quad (1)$$

During the construction of MGs, various additional costs are incurred and are determined as follows:

$$K_{MG} = (1 + \frac{k_{add.}}{100})C_{ed}N_{ed}; \quad (2)$$

where C_{ed} is the cost of the power device, sum. N_{ed}- number of power devices, pcs. $k_{add.}$- additional cost relative to MG cost,%.

$$C_{ed} = k_{ed}^{relative.}N_{ed}^{relative.}; \quad (3)$$

$k_{ed}^{relative.}$ specific cost of the power device relative to the installed capacity, sum/kW.

Annual costs of electricity generation are determined as follows:

$$E_t^{total.} = E_t^{operational} + E_t^{amort.}; \quad (4)$$

$$E_t^{operational.} = E_t^{major\ repairs.} + E_t^{present.repairs.} + E_t^{mounth} + E_t^{fuel} + E_t^{etc.}; \quad (5)$$

$$E_t^{major\ repairs.} = K_\Sigma^{constr.} \cdot \frac{\mu_{major\ repairs.}}{100}; \quad (6)$$

$$E_t^{present.repairs.} = K_\Sigma^{constr.} \cdot \frac{\mu_{resent.repairs.}}{100}; \quad (7)$$

$$E_t^{fuel} = B_t^{fuel}C_{fuel.t}; \quad (8)$$

B_t^{fuel}- annual fuel consumption, t. $C_{fuel.t}$- fuel price for t years, sum/t.

$$C_{fuel.t} = C_{fuel.t}(1 + \frac{\varepsilon_{inf}}{100})^{t-t_{b.operation.}}; \quad (9)$$

Typically, other costs account for 1÷5% of other operating costs and are determined as follows:

$$E_t^{etc.} = (0{,}01 \div 0{,}05)\left(E_t^{major\ repairs.} + E_t^{present.repairs.} + E_t^{mounth} + E_t^{fuel}\right) \quad (10)$$

$$E_t^{amort.} = K_{amort.}\sum_{t=t_{b.constr.}}^{t_{b.constr.}} K_t \frac{(1+\frac{\varepsilon_{inf}}{100})^{t-t_{finish.constr..}}}{(t_{b.constr.}+T_{calc.}-t_{finish.constr.})}; \quad (11)$$

$K_{amort.}$- Depreciation (amortization) coefficient (usually in the range of 1÷1.5).

A soft loan can be obtained by the construction organization as the construction of the MG will initially require a large amount of money.

Credit indebtedness for t year (D_t^{credit}) is calculated as follows:

$$D_t^{credit} = D_{t-1}^{credit} + K_t^{credit}; \quad (12)$$

K_t^{credit}- loan amount received, sums.

$$B_t^{credit} = D_{t-1}^{credit}\frac{\mu_{credit}}{100}; \quad (13)$$

Since the installed capacity in MG is not very large, the amount of credit will also not exceed 10 years.

The profit (N^{profit}) from the built MG is determined as follows:

$$N^{profit} = W_t^{e.}C_t^{e.} + W_t^{f.e}C_t^{f.e}; \quad (14)$$

$W_t^{e.}$- t is the amount of electricity produced over time, kWh; C_t^{e}-price of electricity for time, sum/kWh;

The price of electricity varies depending on inflation and is determined as follows:

$$C_t = C_{t\ b.constr.}(1 + \frac{\varepsilon_{inf}}{100})^{t-t_{b.constr.}}; \quad (15)$$

$C_{t\ b.constr.}$ - price of electricity at the beginning of construction works in MG, sums.

Value added tax (VAT):

$$T_t^{VAT} = P_t^{profit}\frac{\mu_{VAT}}{100}; \quad (16)$$

t sales tax during the year:

$$T_t^{sell} = P_t^{profit}\frac{\mu_{sell}}{100}; \quad (17)$$

Property tax:

$$T_t^{estate} = C_t^{balance}\frac{\mu_{estate}}{100}; \quad (18)$$

$$C_t^{balance} = C_{t-1}^{balance} + \sum_{t=t_{b.constr.}}^{t_{finish.cons.}} K_t(1 + \frac{\varepsilon_{inf.}}{100})^{t-t_{finish.cons.}} - \sum_{t=t_{finish.cons.}}^{t} E_t^{amort.} + B_t^{credit} + B_t^{p.b.p.credit};$$

t year land tax:

$$T_t^{area} = S_{area}\mu_{area}(1 + \frac{\varepsilon_{inf.}}{100})^{t-t_{b.constr.}}; \quad (20)$$

S_{area}- land area allocated for MG, ha; μ_{area} - land tax rate, sum/ha.

Earnings for the year: $P_t^{earning} = P_t^{profit} - T_t^{sell} - И_t^{total.}$; (21)

Income tax: $\mathrm{T}_t^{earning} = P_t^{tax}(1 + \mu_{MG\ area.})/100$; (22)

Net profit from RES-based MG:

$$N_t^{net} = N_t^{until\ tax.livied} - \mathrm{T}_t^{earning}; \quad (23)$$

The liquidation value (L_t) of MG is calculated for the last year:

$$L_t = \sum_{t=t_{b.constr.}}^{T_{calc.}+t_{b.constr.}} K_t(1 + \frac{\varepsilon_{inf.}}{100})^{t-t_{b.constr.}} - \sum_{t=t_{b.constr.}}^{t_{b.constr.}+T_{calc.}} E_t^{amort.}\left(1 + + \frac{\varepsilon_{inf}}{100}\right)^{t-t_{b.constr.}}; \quad (24)$$

MG payback period:

$$\sum_{t=t_{b.constr.}}^{T_{calc.}} (N_t^{net} + E_t^{amort.} + L_t - \mathrm{K}_t^{total} - \mathrm{B}_t^{credit} - \mathrm{B}_t^{p.b.p.credit}\left(1 + \frac{\varepsilon_{earning}}{100}\right)^{t_{b.constr.}-t} = 0; \quad (25)$$

Net present value (NPV) for MG:

$$\mathrm{NPV}_{MG} = \sum_{t=t_{b.constr.}}^{T_{calc.}+t_{b.constr.}} (P_t^{net} + E_t^{amort.} + L_t - \mathrm{K}_t^{total}) \cdot \left(1 + \frac{\varepsilon_{earning}}{100}\right)^{t_{b.constr.}-t}; \quad (26)$$

$$\mathrm{IRR}_{MG} = \sum_{t=t_{b.constr.}}^{T_{calc.}+t_{b.constr.}} (P_t^{net} + E_t^{amort.} + L_t - \mathrm{K}_t^{total})\left(1 + \frac{NPV_{MG}}{100}\right)^{t_{b.constr.}-t}; \quad (27)$$

For MG construction to be effective, Internal rate of return (IRR) and NPV must aim for → max, This → 0. The necessary values for all calculations were entered into Excel.

RESULTS AND DISCUSSIONS

The selected power plants generate an average of the following amount of electricity per year (Figure 2).

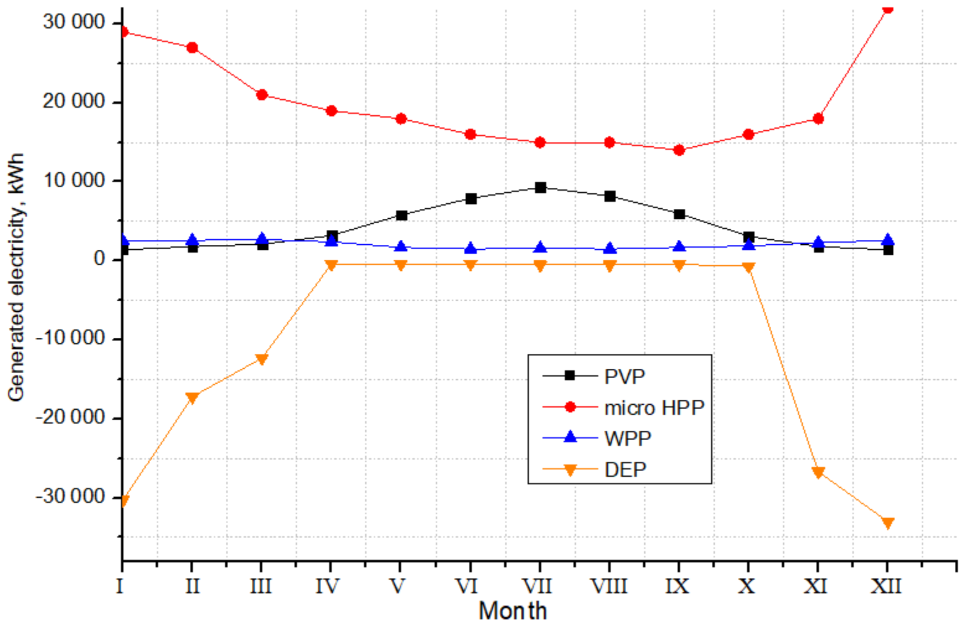

FIGURE 2. The average annual amount of electricity produced by power sources in MG

There are times during the year when the capacity of the proposed power plants (WPP, PVP or microHPP) cannot fully cover the load. Although expensive at such times, DEP and AB (mini HPC) are required to increase the reliability of the power supply system. To make up for the lack of power shortages, the number of ABs must first be determined.

With the development of market relations, consumers of electricity in MG pay special attention not only to the quality of electricity generated, but also to its cost.

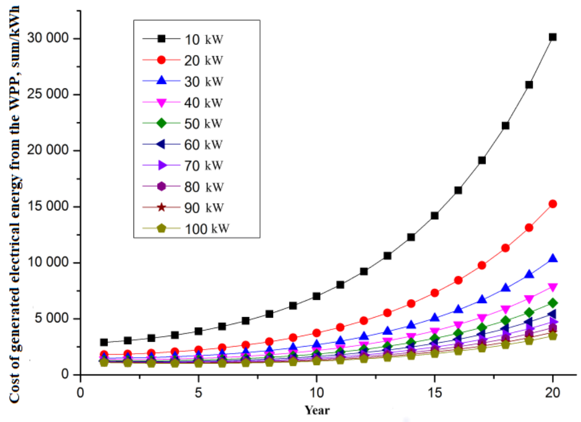

FIGURE 3. Graph of the cost of electricity generated by WPP as a function of its capacity.

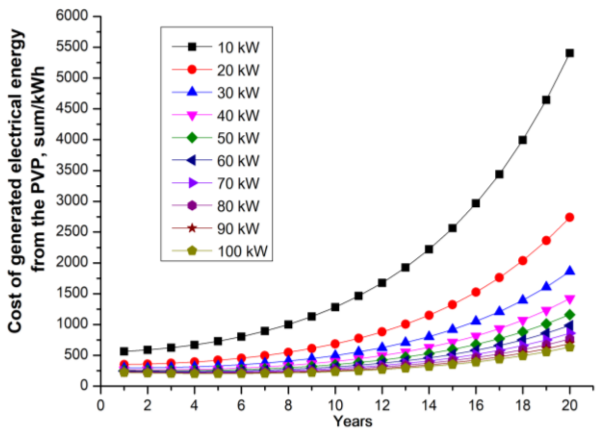

FIGURE 4. Graph of the cost of electricity generated by PVP as a function of its capacity.

For this purpose, it was determined that the cost of electricity generated depends on the installed capacity (Figures 3 and 4).

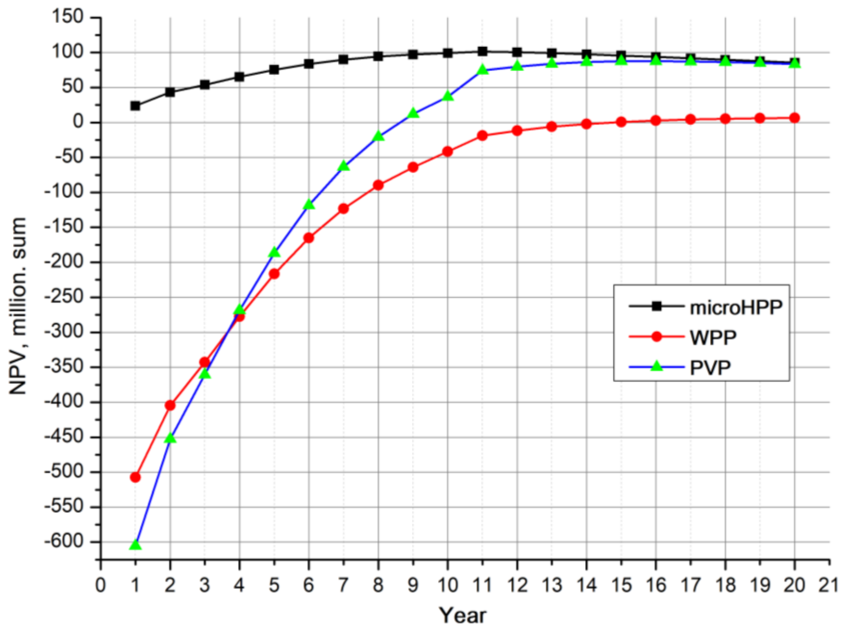

FIGURE 6. The payback period of power plants with an installed capacity of 100 kW

As can be seen from Figure 6, the MGs first cover the microHPP and then the PVP themselves faster than the WPP. The power of all power plants is selected the same, ranging from 50 kW at the same value.

TABLE 1. Cost of 1 kWh of electricity produced by MG in the selected area (feeder SHFK)

Type of power sources in MG	Annual average production amount of electricity (kWh)	Cost of electricit, Uzb. sum/kWh	
		One workforce is taken into account	One workforce is not taken into account
MicroHPP	240 000	108.05	47.78
WPP	25 000	2974.37	2356.61
PVP	52 000	1051.2	753.9
DPP	75 350	2788.5	2579.4

CONCLUSIONS

Due to the fact that the calculation method takes into account several factors (their borrowing capacity due to the cost of RES, inflation, labor and future taxes), the cost of electricity expected to be generated in MG may be slightly different from today (Table 1). According to the results of the calculations, the optimal option of selecting a micro-hydropower plant as a source of electricity for an autonomous micro-electrical system in the technically and economically selected area was determined.

RES at MG generates an average of 317 000 kWh of electricity per year, compared to 95.1 million kWh per year at current electricity prices. equal to sum. The cost of building the MG is estimated at 1.2 billion. sums. If 0.5% (~7 million sums) per year is allocated for additional costs for electrical equipment, then 28.186 million soums per year. sums. In the future, the expected benefits may increase through the introduction of differentiated tariffs in the electricity system.

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