



# Development of High Efficiency and Cost Effective Energy Generation Novel Technology

**Zohrab Melikyan<sup>\*</sup>, Siranush Egnatosyan**

“Heating Ventilation and Air Conditioning” Department, National University of Architecture and Construction of Armenia, Yerevan, Republic of Armenia

**Email address:**

[zohrabmelikyan@yahoo.com](mailto:zohrabmelikyan@yahoo.com) (Z. Melikyan), [siranushegnatosyan@nuaca.am](mailto:siranushegnatosyan@nuaca.am) (S. Egnatosyan)

<sup>\*</sup>Corresponding author

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**Abstract:** During last, many years the electrical energy is generated in large Thermal Power Plants (TPP) and Nuclear Power Plants (NPP). Thermal Power Plants are the main electricity generating stations that are functioning based on the principle of thermal energy conversion into mechanical and finally into electrical energy. The noted conversion is accomplished by the condensation type of thermodynamic cycle that is called “Rankin” cycle. There are in use Co - generation heat and power plants too, which are functioning based on “Bryton” thermodynamic combined cycle. These plants are assigned for simultaneous generation and distribution of thermal and electrical energy. For this reason, they are more efficient. However, all mentioned cycles and conforming to them power plants serving for generation and distribution of large quantity of electricity from energy generating centralized stations to large number of consumers, which are located in significantly long distance from generating stations. The analysis of existing practice of use of mentioned types of electricity generating powerful centralized stations because of large losses of energy are not enough efficient and cost effective. For instance, the COP of electricity generating station, working by well-known Rankin cycle, makes only 30%, because about 70% of produced thermal energy should be lost to the surrounding environment for providing required conditions of electricity production. It is obvious that such big energy losses extremely pollute the environment, provoke global climate change and forces Governments adopting more forceful approaches to reduce carbon and other harmful gases rejections, increase efficiency of energy generation and improve environmental situation. For this reason, after having studied the potential possibilities of reduction of harmful gases rejections and increase of energy efficiency of electricity generation conventional mods the authors of this article became convinced in impossibility of assigned task and have decided to suggest novel and higher efficiency technology for electric energy generation. From this, point of view this article may become a guideline that can help to improve the present environmental and economic situations.

**Keywords:** Compressor, Expander, Air Receiver, Energy Producing Separate Equipment, Power, Pressure, Assemblage

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## 1. Introduction

The problems of generation, transportation and consumption of large quantity of electric energy without big difficulties became the main reason for inventing and using of different types of fossil fuels consuming powerful electric stations [1]. However, in spite of many advantages these electric stations are characterized by many disadvantages, which drastically decrease their effectiveness and create serious social and economic problems. The primary problems are the harmful toxic emissions created from the combustion of different fossil fuels such as coal, natural gas, sulfur dioxide

(SO<sub>2</sub>), nitrogen oxides (NO<sub>x</sub>), and greenhouse gases, like carbon dioxide (CO<sub>2</sub>) gas [2]. The amount and nature of emissions depend on type of consumed fuel. For avoiding of raised problems and simplifying structures of electricity generating stations it is suggested to develop electricity generating stations consisting of energy producing separate small equipment that can be used for assembling electricity generating technologies. Nevertheless, in all cases the energy efficiency and cost effectiveness stay the main requirements for adopting of developed systems into relying. From this point of view the simplicity of structure and effectiveness of energy generating new technology, based on assemblage of energy generation stations assembled from energy producing

separate small equipment is the question of critical importance. As such, equipment can serve well-known reciprocated and turbo compressors, turbo expanders, electricity generators and various auxiliary equipment that are in production almost in all countries [3-5].

The primary emissions to surrounding environment from the combustion of fossil fuels or biomass are sulfur dioxide (SO<sub>2</sub>), nitrogen oxides (NOX), particulate matter (PM), carbon monoxide (CO), and greenhouse gases, such as carbon dioxide (CO<sub>2</sub>) and other environmentally harmful gases [2].

## 2. Developing of Electricity Generating Station, Assembled From Energy Producing Separate Small Equipment

The Figure 1 shows one of possible schemes of an electricity generating station, assembled from separate equipment.

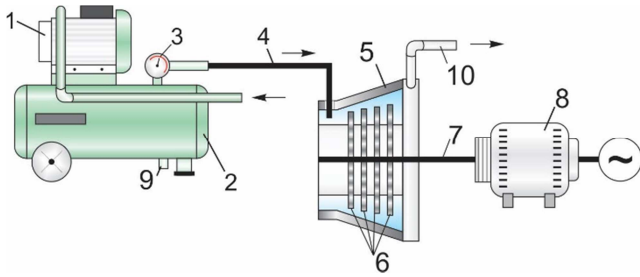


Figure 1. Principal scheme of suggested electricity generating new station.

1-air compressor, 2- receiver of compressed air, 3- air pressure regulating gauge, 4-compressed air turbo expander's feeding pipeline, 5- turbo expander of air, 6- reactive blades of air turbo expander, 7- electricity generator's rotor driving shaft, 8- electricity generator, 9- condensate periodically removing automatic valve, 10- outlet of low pressure used air.

## 3. Operation of Energy Generating New Station, Functioning by Novel Technology

According to the suggested novel technology, the electrical energy generating station operates in the following way: the air compressor (1) compresses outside or inside air up to pressure  $P_{exp.in}$  and forces into the receiver (2) of compressed air. The volume of the receiver (2) depends on designed working regime of the station that conforms to the regime of generated electricity consumption, which in its turn depends on diagrams of energy consumers. The regulator (3) automatically controls the pressure of air in the receiver (2). The compressed air by the high-pressure air's inlet tube (4) from the receiver (2) of compressed air is forced into the turbo expander (5) where it expands adiabatically up to the atmospheric pressure. Because of air expansion, the reactive blades (6) of turbo expander are rotating and spinning the shaft (7) of electric generator (8). Because of rotation, the electric generator (8) produces electricity, the specific quantity  $l$ , kJ/kg

of which is determined by the following equation [6-8]:

$$l = \frac{ZRT_{exp.in}}{k-1} \left[ 1 - \left( \frac{P_{exp.out}}{P_{exp.in}} \right)^{\frac{k-1}{k}} \right] \quad (1)$$

where:

$Z=1.04$ -compressibility factor of air [9],

$R= 287 \text{ J/(kg}^\circ\text{C)}$  - gas constant of air [10, 11],

$T_{exp.in}$  – initial temperature of air at the inlet of turbo - expander,

$P_{exp.in}$  – initial pressure of the atmospheric air at the inlet of turbo-expander,

$P_{exp.out}=1\text{bar}$  – pressure of the air at the outlet of the turbo-expander,

$k=1.4$  adiabatic or isentropic exponent for air [10].

Temperature of air at the inlet of turbo-expander  $T_{exp.in}$ , can be determined by the following equation [7-9]:

$$T_{exp.in} = T_{air.out} \left( \frac{P_{atm}}{P_{exp.in}} \right)^{\frac{1-k}{k}} \quad (2)$$

where:

$T_{air.out}$  – outside air temperature, is adopted (for summer time:  $T_{air.out}=35+273=308^\circ\text{K}$ , and for winter time:  $T_{air.out}=273+(-19)=254^\circ\text{K}$  [12]),

$P_{atm}=1\text{bar}$  - pressure of atmospheric air.

The results of calculations, made by equations (1) and (2) are shown on the Figure2 in form of diagrams.

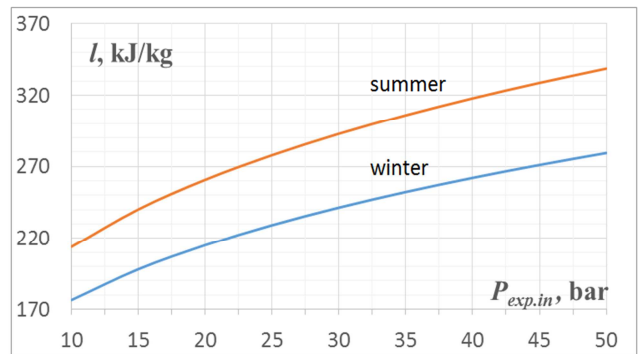
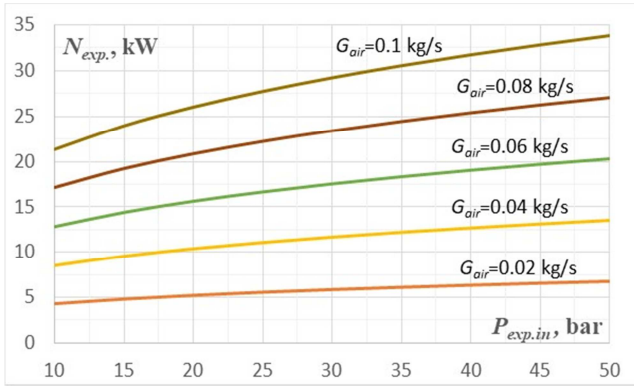


Figure 2. Diagram of values of specific energy  $l$ , kJ/kg, produced in summer and winter periods, depending on pressure of air  $P_{exp.in}$  at the inlet of air expander.

As show the diagrams of Figure 2, because of higher temperatures of air at the inlet of the turbo-expander the quantities of produced specific energy, in summertime in 17% are higher, than in wintertime. That is to say, the efficiency of turbo expander in summertime is higher, than in wintertime. Taking into account that whole the air of the receiver in quantity  $G_{air}$  kg/s, is expanded in turbo-expander, the absolute value of electric power  $N_{exp.}$ , kW, produced by the turbo expander will make the values represented by the diagram of Figure 3.



**Figure 3.** Power developed by turbo expander depending on quantity of expanded air.

The power, developed by turbo expander is determined by the equation as follows:

$$N_{exp} = G_{air} \cdot l \quad (3)$$

where:

$G_{air}$  - quantity of air, expanded in the turbo expander, kg/s.

The Figure 3 shows that power, produced by turbo expander depends on air quantity  $G_{air}$ , kg/s, which is supplied into the turbo expander. For example, capacity of the receiver, which is prescribed for screw type compressor ABT 500/2000 of "Fiak" company, is 500l, and the air productivity of the compressor is 2000 l/min or 0.04kg/s with pressure 10 bar [13] develops power  $N_{exp}$  the value of which, according to equation (3), makes:

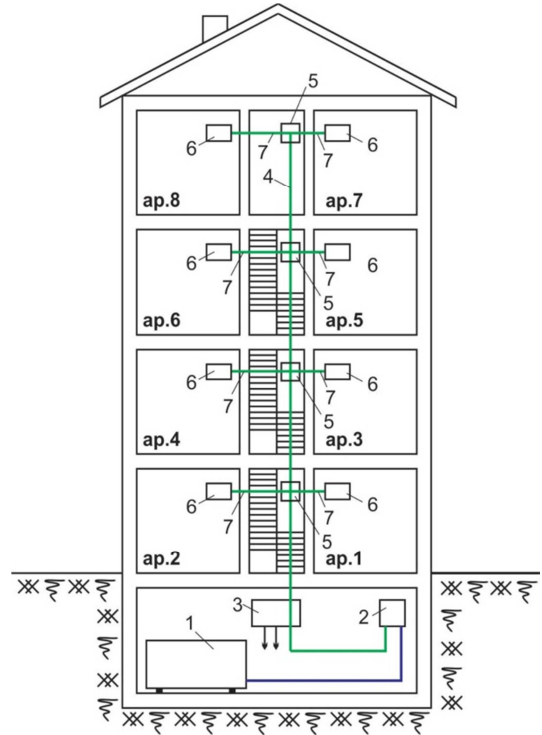
$$N_{exp} = 0.04 \cdot 214 = 8.56 \text{ kW.}$$

#### 4. Design of Electricity Station on Example of a Low Rise Residential House

The order of design of electricity station for a house or for other electricity consumer is the following:

- 1) Determination of electricity demand of the consumers;
- 2) Developing of electricity supplying and distributing scheme by all consumers;
- 3) Determination of characteristics of electricity producing separate small equipment and their selection;
- 4) Determination of energy-economic characteristics of designed electricity station.

An example of electric station designed for a 4 story residential house is shown in Figure 4.



**Figure 4.** Scheme of 4 story residential house with electricity generating new station and electricity supplying network.

1- electricity generating new station with transformer of the electric station, installed in the basement of 4 story residential house, 2- main electricity meter of the house, 3- main distributor of electricity, 4- electricity distributing main cord, 5- electricity distributors by stories (floors), 6- electricity meters by apartments, 7- distribution cords.

Automated receiver of compressed air controls the regime of operation of energy producing main small equipment like compressor, and high-pressure air turbo expander in the following way: a day is divided in three intervals of time with 8 hours duration each. During each interval, a process is executed. So in first 8 hours interval the compressor operates and fills up the receiver with compressed up to 10 bar air, afterwards the compressor automatically stops operating and second 8 hours interval starts, during of which through open automatic valve the high-pressure air expands and through air turbo expander paces from the receiver into atmospheric air and during second 8 hours electricity generation takes place. Taking into consideration above explanations the equation (1) can be transformed into the following one:

$$l = \frac{\tau \cdot ZRT_{exp.in}}{k-1} \left( 1 - \left( \frac{P_{exp.out}}{P_{exp.in}} \right)^{\frac{k-1}{k}} \right) \quad (4)$$

where:

$\tau$  = 8 hours or  $\tau = 28800$ s – duration of interval of time when the station generates energy.

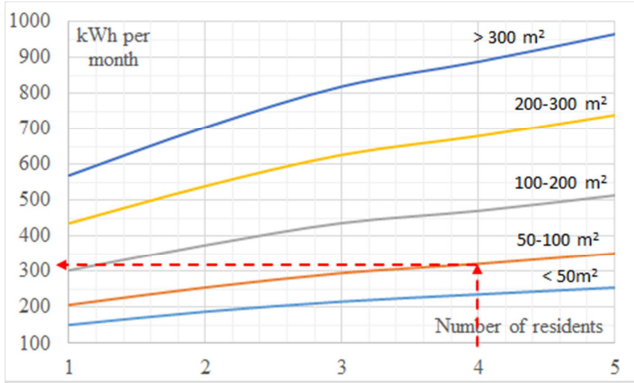
The power of electric station  $N_{st}$  of the considered building is determined by the following equation:

$$N_{st} = \frac{n_{ap} \cdot q_{el.dem}}{H} \quad (5)$$

where:

$n_{ap}$  - number of apartments of the building,  
 $q_{el.dem}$  - electricity demands by each apartment per month,  
 $H=720$  hours- duration of a month in hours.

According to diagram of Figure 5, the electricity demands of apartments with 4 residents each and 100m<sup>2</sup> of surface makes  $q_{el.dem} = 320$  kWh/month.



**Figure 5.** Normative consumption of electric energy in residential houses depending on number of residents and surfaces of apartments [14].

Substitute of above data in Eq. (5) and making calculations, will determine the following power, generated by the designed electric station:

$$N_{st} = \frac{8 \cdot 320}{720} = 3.56 \text{ kW}$$

## 5. Tariff of Electricity, Generated by Developed New Station

The tariff of energy is the average cost of 1 kW of energy, generated by electric station. It is determined by the following expression:

$$T_f = \frac{\frac{\Sigma K}{Y} + \Sigma U}{\Sigma l} \quad (6)$$

where:

$\Sigma K$  - total capital cost \$, of the assembled power plant,  
 $\Sigma U$  - annual operational cost of the power plant, \$/year,  
 $Y$  - capital investment's payback period, which is selected to be equal to the life cycle duration of the station or any other period in case of which the cost of electricity supply  $T$ , \$ becomes affordable for consumers and acceptable for investors, year,

$\Sigma l$  - quantity of energy, kWh/year, generated by electric station during one year.

The total capital cost  $\Sigma K$  \$, of the assembled power plant, is the sum of energy producing separate small equipment that is determined by the following expression:

$$\Sigma K = (K_{comp} + K_{tur.exp} + K_{el.gen}) \cdot 1.4 \quad (7)$$

where:

$K_{comp}$  - cost of compressor with receiver, \$,

$K_{tur.exp}$  - cost of turbo expander, \$,

$K_{el.gen}$  - cost of electricity generator, \$,

1.4- electric station's assembling and testing labor cost and in addition, extra expenditures factor.

### 5.1. Cost of Compressor and Receiver Is Defined by the Following Production

$$K_{comp} = C_{comp} G_{air.comp} \quad (8)$$

where:

$C_{comp} = 2.92$  \$/(l/min) specific cost of compressor [15],

$G_{air.comp}$  - air productivity of compressor, depending on the quantity of air passing through the air expander. The air productivity of the compressor can be determined by the following production:

$$G_{air.comp} = \frac{N_{exp} 1000 \cdot 60}{l_{exp} \rho_{air}} = \frac{3.56 \cdot 1000 \cdot 60}{214 \cdot 1.2} = 831.78 \text{ l/min}$$

Substitute of values  $C_{com}$  and  $G_{air.com}$  into (8) will obtain the capital cost of the compressor:  $K_{comp} = 2.92 \cdot 831.78 = \$2429$

### 5.2. Cost of Turbo Expander Is Defined by the Following Production

$$K_{tur.exp} = C_{exp} \cdot N_{exp} \quad (9)$$

where:

$C_{exp}$  - specific cost of turbo expander which according to [16] makes from \$600 to \$2300. The average specific cost makes 1450\$/kW,

$N_{exp}$  - power of turbo expander, which according to (5) for the 8 apartments of 4 story house makes 3.56kW.

Substitute of values  $C_{exp}$  and  $N_{exp}$  into (9) and making calculations will obtain the following capital cost of the turbo expander:

$$K_{tur.exp} = 1450 \cdot 3.56 = \$5162$$

### 5.3. Cost of Electricity Generator

Because of absence of mass manufacturing of electric generators, which are similar to the electric generator which is invented in this article, the cost of electricity generator used in considered electric station is taken about the same as the cost of electric motor of the same 4 kW power, which is produced by the company "Energodrive" makes  $K_{el.gen} = \$134$  [17].

Substitute costs of all equipment in (7) will determine the following total capital cost  $\Sigma K$  \$, of the assembled power plant:

$$\Sigma K = (2429 + 5162 + 134) \cdot 1.4 = \$10810$$

Total annual operational cost of considered power plant consists only of current repair cost of new electric station, which does not exceed 4%. For this reason, the current repair cost is neglected.

Quantity of energy, generated by electric station during one year makes:

$$\Sigma l = \tau_{year} N_{st} m_{op.} = 8640 \cdot 3.56 \cdot 0.8 = 24607 \text{ kWh/year}$$

where:

$\tau_{year}$  - total number of working hours of the station during a year,

$m_{op.}=0.8$ - coefficient of yearly operating hours of the station.

Conformably, the tariff of energy, generated by suggested electric station makes:

$$T_f = \frac{10810}{25 \cdot 24607} \approx 0.018 \text{ \$/kWh}$$

The obtained value of the electricity tariff proves that developed electric station, based on suggested new technology is more efficient compared to existing in Armenia powerful centralized electric stations functioning by Rankin and combined cycles the electricity tariff of which makes 0.08\$/kWh which in 4.44 times is lower, than the tariff of electricity, generated by centralized thermal power plants.

## 6. Conclusions

It is the first attempt to develop electricity station, assembled from energy producing small equipment that can become the first-born one in the range of new generation of electricity producing local facilities.

With successful start of use of suggested new technology new era of local, private and cheap electricity stations with very high efficiency and low cost of produced energy will start.

The tariff of electricity, produced by suggested novel technology will be fourfold lower.

The suggested new order of operation of energy producing small equipment can be useful for designers of electric stations.

The most valuable feature of developed new technology is the absence of natural fossil fuel use, which leads to preserving of environment from pollution and keeps stable climate.

The farther development of considered technology will shape a society of cheap energy consumers, cheap electric stations designers and cheap electricity producers that will spur development of economy of countries and will create

prosperous life.

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