# Efficiency of the Energy Complex when Using a Hybrid Mini-HPS in the Republic of Vietnam

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***Abstract*—The article describes characteristic features of the energy system of Vietnam, identified the main problems of energy supply of industrial enterprises of the republic, which are most associated with the wear and tear of electric networks and accidents in the energy system. Industrial enterprises suffer heavy losses due to power outages. The problem of ensuring reliable energy supply to enterprises, especially those with high export potential, can be solved by creating an energy complex with an autonomous source of energy supply. Reduction of fuel consumption at this power plant is achieved by using solar energy to heat air supplied to gas turbine plant. The work of an industrial enterprise, which is part of an energy complex with an autonomous power supply source with a capacity of 5 MW, is considered. The advantage of this scheme is that the steam-gas plant operates independently of external conditions, using natural gas as fuel. The presence of a solar air heater allows you to significantly save fuel by about 10% per year. Simulation and calculation of the process diagram of the hybrid mini-HPS was carried out, the main and auxiliary equipment was selected, and a technical and economic analysis was carried out. It is shown that power supply from the hybrid mini-HPS, the cost of which is 0.034 US dollars per 1 kWh, is more profitable compared to the purchase of electricity at a price of 0.07 US dollars per 1 kWh, and does not depend on the state of electric networks and their accident rate.***

***Keywords*—energy complex, hybrid mini-HPS, solar energy, gas turbine plant**

## I. INTRODUCTION

Vietnam is thedeveloping countrylocated in Southeast Asia. However, the growth of industrial production is largely constrained by the fact that the existing power system cannot quickly increase the required capacity. Vietnam's energy is based mainly on coal and gas-fired thermal power plants. Their share in the total is about 75%. In addition, hydropower is developed (18%), about 5% comes from renewable energy sources - solar, wind, biomass energy. Electricity imports from China and Laos are 2%. Power plants with a total capacity of 54 GW operate as part of a centralized power system, the length of 500 kV transmission lines is more than 3,800 km [1].

According to Vietnam Power Group, the country's largest electricity producer and sole distributor, Vietnam needs a total capacity of about 96.5 GW by 2025 and 129.5 GW by 2030. To cope with the situation, it is planned to increase the capacity and total electricity production from renewable sources from approximately 58 billion kWh in 2015 to 186 billion kWh by 2030, as well as the share of electricity imports from China and Laos to 9% as a temporary solution [2].

It is planned to achieve this level of energy production both through the construction of large-capacity power plants and through the development of small distributed energy.

The construction of large power plants significantly increases the load on network infrastructure, which is very worn out and requires large investments. In addition, the requirements for ensuring the reliability of electricity supply and the quality of electricity are increasing, which requires the electricity industry to take appropriate measures in the construction of the power system and electric networks. The construction of small autonomous energy facilities that provide energy to the enterprise or housing estate and are in close proximity to the consumer is promising in this situation. Therefore, it is relevant to develop technological solutions for energy supply of enterprises adapted to regional climatic and economic conditions. In this regard, the purpose of this work is to model the technological scheme of the energy complex, which includes an industrial enterprise and a hybrid autonomous power plant, to evaluate the efficiency of the complex in the conditions of the Republic of Vietnam.

### *A. Development of small distributed generation*

Given the threats of climate change, natural disasters and terrorism, many countries, including Viet Nam, are conducting research to develop an "adaptive planning" option that includes local distributed generation models that provide uninterrupted electricity to especially important consumers, such as police stations, fire departments and hospitals. In addition, it is advisable to use renewable energy sources at small distributed generation facilities. The modeling technological schemes of power plants combining various energy resources, including renewable (solar and wind) are available in articles of many scientists from around the world [3, 4, 5, 6, 7, 8, 9]. For Vietnam, such sources are mainly solar and wind energy. The results of studies on the feasibility and expediency of using these resources are presented in detail in works [10, 11, 12, 13]. This paper considers the use of solar energy in small power plants with a capacity of up to 25 MW, operating autonomously or connected to the grid.

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The solar energy availability in Vietnam is quite high - the average total solar radiation in the republic ranges from 1346.8 to 2153.5 kWh/m2 per year with an average annual number of solar hours 1600-2720 hours per year [14]. It is considered that the commercial use of the solar energy is economically feasible with an average total intensity of direct solar radiation of more than 1200 kWh/m2.

### B. *Energy supply problems of industrial enterprises in Vietnam*

The economic policy of Vietnam is aimed at transforming the country from agrarian to industrial with a developed manufacturing industry, mechanical engineering, light and food industries, and the production of textiles, clothing, shoes and food products has significant export opportunities. The intensive development of these industries requires efficient and reliable energy supply. However, Vietnam, like many developing and even industrialized countries, faces serious problems in the energy supply of enterprises and domestic consumers due to power line accidents. Table 1 [15, 16] provides information on the most significant power outages in various countries and in more detail in Vietnam. At the same time, the most serious consequences of the power outage will be for those enterprises that are bound by international obligations and send their products for export.

In accordance with the new Strategy for the Development of Industry of the Republic, all industrial enterprises are divided into 3 groups. The first group includes enterprises with high competitive advantages - processing industries of agriculture and forestry, the production of food, textiles, shoes, wood products, shipbuilding, the production of agricultural machinery, electronics assembly and the craft industry. The second group unites enterprises of the main industry group - metallurgical, energy, chemical and petrochemical. The third group includes enterprises with high development potential in the future - electronics production, telecommunications, information technology. It can be assumed that first of all, the enterprises of the first group need reliable and high-quality energy supply.

Statistics show that in Vietnam, economic losses from energy outages account for 2.2 per cent of the total sales for the year [17]. Therefore, for enterprises of various industries, the choice of a source of energy supply is important. A reliable and promising option in this situation is the construction of its own mini-HPS, located near of the enterprise. This work for the first time proposes a technological solution for the power supply of the enterprise, taking into account the conditions for the supply of fuel, changes in air temperature and the intensity of direct solar radiation during the year. Such a solutions can be implemented in other countries with similar climatic and economic conditions, therefore the development of a methodology for calculating and selecting equipment for hybrid mini-HPS is an relevant task.

TABLE I. ACCIDENTS IN POWER SUPPLY SYSTEMSFOR 2011-2020 YEARS.

| **Country (region)** | **Date of accident** | **Duration of shutdown, h** | **Number of victims, million persons** |
|---|---|---|---|
| Mexico and USA | 8.09.2011 | 12 | 2.7 |
| Brazil | 4.02.2011 | 16 | 53 |
| India | 30.07. 2012 | 15 | 620 |
| Philippines | 6.08.2013 | 12 | 8 |
| Thailand | 2013 | 10 | 8 |
| Bangladesh | 1.11.2014 | 24 | 150 |
| Pakistan | 26.01.2015 | 2 | 140 |
| Holland | 27.03.2015 | 1 | 51 |
| Ukraine | 21.11.2015 | 6 | 1.2 |
| Kenya | 7.06.2016 | 4 | 10 |
| Sri Lanka | 3.03.2016 | 16 | 10 |
| South Australia | 28.09.2016 | 6.1 | 1.7 |
| United States (New York) | 1.03.2017 | 11 | 21 |
| Uruguay | 26.08.2017 | 4 | 3.4 |
| United States (Southeast) | 10.09.2017 | 5 | 7.6 |
| Sudan | 10.01.2018 | 24 | 41.5 |
| Azerbaijan | 3.07.2018 | 8 | 8 |
| Brazil | 21.03.2018 | 1 | 10 |
| United States (Texas) | 15-21.02. 2021 | 120 | 2.7 |
| Canada (British Columbia) | 20.12.2018 | 4 | 0.6 |
| Vietnam | 22.05.2013 | 10 | 10 |
| Vietnam (Tanshon-nyat Airport) | 22.11.2014 | 5 min | 10 |
| Vietnam (Dyk Hoa district) | 13.11.2019 | 3 | 0.6 |
| Vietnam (Hong Tre Island) | 14.08.2020 | 24 | 0.5 |
| Vietnam (Dang) | 13.06.2019 | 24 | 1.134 |
| Vietnam (Bindin Province) | 9.11.2020 | 72 | 0.315 |

## II. Materials and Methods

### A. Selection of industrial enterprise

The following object was chosen to model the mini-HPS - a leather and vulcanized sports footwear production plant located in the province of Vinh Long, the production of which is 25 million pairs of shoes per year, and the export annual turnover reaches 230 million US dollars. The plant requires an electric capacity of 5 MW. The economic impact of the blackout on the facility is 5.6 million US dollar per year.

### B. Hybrid mini-HPS technological scheme

As an autonomous object operating as part of the power complex, it is proposed to use a hybrid mini-TPP operating on the basis of a gas turbine plant (GTU) with a solar air heater. The feasibility of applying this solution in the economic and climatic conditions of Vietnam was justified earlier [18], the technological scheme is shown in Figure 1.

The main flow parameters and equipment characteristics are given in Table 2. The plant works as follows: air I is compressed into compressor 1 of gas turbine plant, compression ratio is 10.6. Then the compressed air flow is separated - one part, in this case, constituting 10% of the total air flow, is directed to the solar heater 3 located on the tower 4, and the other part is supplied to the mixer 5. The solar radiation flow enters the surface of the heliostats 2, is reflected and concentrated on the surface of the solar air heater. The outer receiving surface transfers heat to the porous insert, through the pores of which heated air passes. Principle of operation of solar air heater for gas turbine plant is presented in detail in works [19, 20, 21, 22, 23], and detailed calculation for these conditions - in earlier work of authors [24]. Air heated to high temperature is directed to mixer 5 and then to combustion chamber 6, where fuel II is simultaneously supplied. The gas mixture obtained during fuel combustion is supplied to gas turbine 7 which is connected to generator generating electric energy. The gases exiting the turbine 7 are directed to the recovery boiler 8, where the recovery of residual heat of the gases generates steam to the steam turbine to generate additional energy. From the recovery boiler, gases III enter the atmosphere.

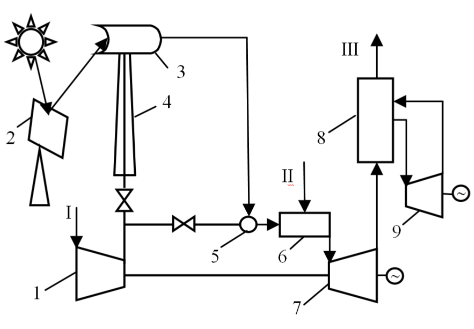


Fig. 1. Technological scheme of hybrid mini-HPS.

The following algorithm is proposed for calculation of hybrid mini-TPP based on steam-gas plant. At the first stage, a gas turbine and a compressor are selected for the required electric power, for which the air flow rate and compression ratio are known. Compressor calculation is carried out according to known formulas [25, 26]. As a result, the air temperature downstream of the compressor and the internal power consumed by the compressor are determined. The energy balance can be represented by the equation:

$$Q_{M1}H_1 + E_1 = Q_{M2}H_2, \tag{1}$$

where $Q_{M1}$, $Q_{M2}$ is the mass air flow rate at the compressor inlet and outlet, respectively, kg / s; $H_1$; $H_2$ is the enthalpy of air at the compressor inlet and at the outlet, respectively, kJ / kg.

The fraction of air supplied to the solar air heater is determined by the previously obtained dependence [24] taking into account the required temperature of heated air at the outlet. The energy balance of a solar air heater consisting of a porous insert, the outer side of which is heated by solar radiation, is described with the equation:

$$Q_{S21}H_2 + Q_2 = Q_{S21}H_3, \tag{2}$$

where $Q_{S21}$ is the mass flow rate of air at the entrance to the solar air heater and at the exit from it, kg/s; $H_3$ is the enthalpy of air at the exit from it, kJ/kg; $Q_2$ is the power of solar radiation spent on heating air $Q_{S21}$, kW.

The following dependencies are used to determine $Q_2$. The summary thermal power of the solar receiver $Q_{sum}$ is determined as the sum of the useful heat power $Q_2$ and losses $Q_{los}$:

$$Q_{sum} = Q_2 + Q_{los}. \tag{3}$$

The total thermal power of the solar receiver depends on the parameters of the solar concentrator. The use of a porous tab increases the radiation intensity to $I_k$. The optical and geometric concentration ratios are related to the optical efficiency $\eta_{opt}$ the concentrator system with a porous tab and the radiation beam $I_b$:

$$Q_{sum} = A_r \alpha_r I_k = A_r \alpha_r \eta_{opt} CR_g I_b. \tag{4}$$

The concentration coefficient $CR_g$ in equation (4) can be defined as

$$CR_g = \frac{A_a}{A_r}, \tag{5}$$

where $A_a$ is the collector aperture area; $A_r$ is the area of the receiving surface; $\alpha_r$ is the absorption capacity of the surface; $\eta_{opt}$ is the optical efficiency; $I_b$ is the intensity of solar radiation.

The summary convection coefficient $U_{los}$ is used to account for convection losses at ambient temperature $T_a$. The losses depend on the receiver temperature $T_r$ and the radiation coefficient of the receiver surface $\varepsilon_r$ :

$$Q_{los} = A_r \varepsilon_r (T_r^4 - T_a^4) + U_{los}(T_r - T_a) . \quad (6)$$

The thermal efficiency $\eta_r$ of the receiver and collector can be calculated using the expression:

$$\eta_r = \frac{Q_2}{A_a I_a} = \eta_{opt}\alpha - \frac{\varepsilon_r \sigma (T_r^4 - T_a^4) - U_{los}(T_r - T_a)}{C R_g I_b} . \quad (7)$$

Taking into account the enthalpy of the air at the outlet from the solar heater, which, minus minor losses, is the enthalpy of the air at the inlet to the mixer in front of the combustion chamber, the combustion chamber is calculated.

The enthalpy of a mixture of two streams of air heated by solar radiation and coming from the compressor, respectively, mixing before being fed into the combustion chamber, is determined based on the following balance:

$$Q_{M2} H_4 = Q_{S21} H_3 + Q_{M22} H_2 , \quad (8)$$

where $Q_{M22}$ is the mass flow rate of the remaining air leaving the compressor, kg / s; $H_4$ is the enthalpy of the air mixture, kJ / kg; $Q_{M2}$ is the mass flow rate of the air mixture, kg / s. Values $Q_{S21}$ and $Q_{M22}$ are related with the ratio:

$$Q_{S21} = \varphi Q_{M2} ;$$

$$Q_{M22} = (1 - \phi) Q_{M2} ; \quad (9)$$

where $\varphi$ is the fraction of air directed to the air heater.

The energy balance of the combustion chamber is expressed with the equation:

$$\begin{aligned} & Q_{M2} H_4 + Q_{MF} Q_L = \\ & = Q_{M31} H_{31} + Q_{M32} H_{32} + Q_{M33} H_{33} + Q_{M34} H_{34} = \\ & = \sum Q_{Mi} H_i \end{aligned} , \quad (10)$$

where $Q_{MF}$ is the mass fuel rate consumption, kg/s; $H_{31}$ is the enthalpy of $CO_2$ leaving the combustion chamber, kJ/kg; $H_{32}$ is the enthalpy of $N_2$ leaving the combustion chamber, kJ/kg; $H_{33}$ is the enthalpy of $H_2O$ leaving the combustion chamber, kJ/kg; $H_{34}$ is the enthalpy of excess air leaving the combustion chamber, kJ/kg; $Q_L$ is the lowest heat value of combustion of fuel, kJ/kg; $Q_{M31}$ , $Q_{M32}$ , $Q_{M33}$ are the mass flow rates of fuel combustion products - $CO_2$, $H_2O$, $N_2$, respectively.

The gas turbine operation is characterized by the following balance:

$$\begin{aligned} & Q_{M31} H_{31} + Q_{M32} H_{32} + Q_{M33} H_{33} + Q_{M34} H_{34} = \\ & = E_1 + E_3 + Q_{M31} H_{311} + Q_{M32} H_{321} + \\ & + Q_{M33} H_{331} + Q_{M341} H_{341} \end{aligned} , \quad (11)$$

where $Q_{M341}$ is the mass air flow after the turbine, kg/s; $H_{311}$ is the enthalpy of $CO_2$ at the outlet from the turbine, kJ/kg; $H_{321}$ is the enthalpy of $N_2$ at the outlet of the turbine, kJ/kg; $H_{331}$ is the enthalpy of $H_2O$ at the turbine outlet, kJ/kg; $H_{341}$ is the enthalpy of air at the outlet of the turbine, kJ/kg; $E_3$ is the useful power produced with the turbine, kJ/s.

Steam from the recovery boiler is used to operate an energy steam turbine. The steam spent in the steam turbine enters the condenser, the condensate through the regenerative heater enters the recovery boiler again, and the cycle repeats. The steam power plant, which receives heat from the exhaust gases of a gas turbine engine, allows more efficient use of the thermal energy released during the combustion of fuel. The efficiency of such a double circuit will be higher than the efficiency of a separate gas turbine plant or the efficiency of a separate steam power plant.

Calculation of elements of this scheme and selection of equipment was carried out according to the methods presented in the following works [25, 26], characteristics of the selected equipment and flow parameters for each element are given in Table 2.

TABLE II. EQUIPMENT CHARACTERISTICS AND FLOW PARAMETERS OF HYBRID MINI- HPS

| Equipment name | Temperature, ºC | | Pressure, MPa | | Flow rate, kg/s |
|---|---|---|---|---|---|
| | *at the entrance* | *at the outlet* | *at the entrance* | *at the outlet* | |
| Compressor | 27 | 340 | 0.1 | 1.06 | 18.8 |
| Solar receiver | 340 | 340-650 | 1.06 | 1.06 | 9.4 |
| Combustion chamber | 650 | 1150 | 1.06 | 0.5 | 18.8 |
| Gas turbine | 1150 | 510 | 0.33 | 0.33 | 18.8 |
| Recovery boiler | 510 | 200 | 0.33 | 0.15 | 18.8 |
| Steam turbine (steam parameters) | 350 | 230 | 0.15 | 0.3 | 4.17 |

The gas turbine plant, consisting of a compressor and a gas turbine, has a capacity of 4.6 MW, a steam turbine of 0.95

MW. Thus, the mini-TPP fully meets the needs of the enterprise for electricity.

### C. Cost of energy produced

In this work, the cost of electricity produced was calculated taking into account the provision of solar energy in Vinh Long province according to the formula for the normalized cost of energy, the use of which at the current stage of energy development is justified in the article [27]:

$$LCOE = \left[\sum (Cap_t + O\&M + F_t + Carb_t + D_t)(1+r) - 1\right] / \sum MWh_t(1+r) - t^o \quad ,(12)$$

where $Cap_t$ – full capital expenditures incurred in year $t$; $O\&M_t$ – operating costs in year $t$; $F_t$ – fuel costs per year $t$; $Carb_t$ – cost of paying for greenhouse gases in year $t$; waste management and decommissioning costs in year $t$; $MWh_t$- amount of energy produced per year $t$.

## III. Results and Discussion

Based on calculation of operation parameters, all elements of the scheme presented in Figure 1, its technical and economic assessment was carried out and the cost of energy produced was determined. The full capital costs for the mini-HPS, taking into account the cost of the equipment and its installation, are shown in Table 3. The annual share of capital expenditures was determined on a 5-year basis. Interest on the loan was not taken into account, it was assumed that the investor would profit from the sale of energy produced. The annual operating and maintenance costs are shown in Table 4. The average wage by category of workers in the energy sector of Vietnam, the cost of water, spare parts and repair work were taken into account.

TABLE III. Total Capital Cost of Hybrid Mini-HPS

| **Costs (units of measure)** | **Unit cost, thousand dollars USA** | **Quantity** | **Total amount, thousands of dollars USA** |
|---|---|---|---|
| Specific land value (hectare) | 23.16 | 28 | 648.5 |
| Heliostats (m2) | 0.21 | 8349 | 1753.3 |
| Tower (m) | 19.55 | 47.5 | 928.6 |
| Solar receiver (m2) | 0.28 | 4600 | 1288.0 |
| Gas turbine unit (kW) | 1.25 | 4600 | 5750.0 |
| Piping (kg) | 0.0059 | 63494 | 374.6 |
| Insulation elements (kg) | 0.00708 | 9117 | 64.5 |
| Steam turbine and recovery boiler (kW) | 0.97 | 950 | 921.5 |
| Control and automation (unit) | 724.56 | 1 | 724.6 |
| Total | 12453.6 | | |

Fuel costs were calculated for each month of the year based on the average monthly intensity of direct solar radiation for Vinh Long Province (Figure 2). Natural gas imported from Malaysia is used as fuel in this province. Analysis of the obtained fuel consumption data shows that the lowest consumption occurs during the period (February) when the intensity of solar radiation is high and the air temperature is moderate - not higher than 25 ° C. The summer months are characterized by heavy cloudiness and rainy weather with a high air temperature of more than 35 ° C. During this period gas turbine equipment operates in heavier conditions and fuel consumption increases. The total fuel consumption was determined during the year. The total cost of fuel was $3.68 million per year.

TABLE IV. Annual Operating and Maintenance Costs of Hybrid Mini-HPS

| **Costs (units of measure)** | **Unit cost, thousand dollars USA** | **Quantity** | **Total amount, thousands of dollars USA** |
|---|---|---|---|
| Salary (person) | 0.826 | 12 | 119 |
| Water (MW • h) | 0.000295 | 40296 | 12 |
| Repair of main equipment (kW) | 0.03186 | 4600 | 147 |
| Power control unit maintenance (MW • h) | 0.00295 | 40296 | 119 |
| Repair Equipment (Kit) | 125 | 1 | 125 |
| Total | 522 | | |

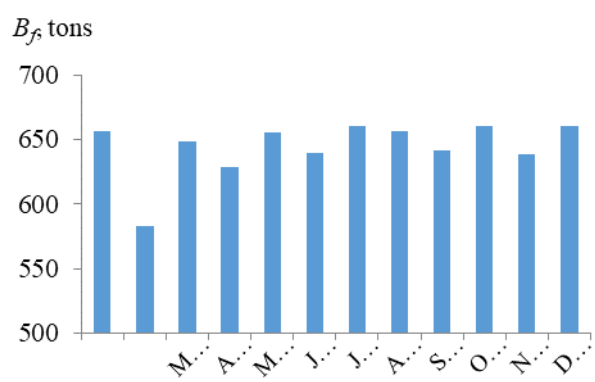


Fig. 2. Fuel consumption at 5 MW mini-HPS.

The annual share of capital expenditure over 5 years was 2.4958 million US dollars. The amount of electricity produced annually is 47,742,000 kWh. When calculated according to the formula (1), the cost of electricity produced amounted to 0.034 US dollars per 1 kWh. The sale price of electricity by the electricity corporation is much higher - 0.07 US dollars per 1 kWh.

Thus, the power supply of the enterprise from its own hybrid mini-HPS is more profitable than the supply of electricity from a centralized power system.

## IV. Conclusion

Energy supply problems of the industrial sector of the Republic of Vietnam related to power outages were identified. The loss of value due to power outages (% of sales of affected firms) in Vietnam is 2.2% per year. A methodology has been developed that allows calculating the scheme of a hybrid mini-HPS and selecting equipment for a steam-gas plant. As an example aor the power supply of a large enterprise, a hybrid mini-HPS technology scheme using 5.5 MW solar power has been proposed. The economic study was carried out, which showed the feasibility of autonomous power supply to this enterprise. The cost of energy produced was 0.034 US dollars per 1 kWh, which is more profitable than buying power from an electricity corporation at a price of 0.07 US dollars per 1 kWh.

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