CONSIDERATIONS REGARDING THE RECOVERING OF POWER TRANSFORMERS POWER LOSSES FROM HV / MV ELECTRIC STATIONS

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Abstract: this paper contains the research results made for SDEE Oradea, basing on the contract no. 30947 / 2010, with subject of "Identifying and experimenting of some solutions of recovering the energy losses in the transformers of electric station". The article is a synthesis of the research rapport elaborated at the end of the research, structured in five parts that deals the useful of the research, evaluating the potential of the released heat in power transformers, existent and possible solutions obtained in electric stations managed by the beneficiary and conclusions.

Key words: power transformer, energy losses, recovery, electric stations, conditioning

1. INTRODUCTION

The importance of the power transformers (PT) for power electric systems is well known [4,7]. The power losses of the PT are taken by the cooling medium (oil in transformer) and are dissipated to the exterior surface of PT pail through convection and radiation. To do exceed the optimum temperature of the oil, the excess heat flux must be dissipated. This is realized by starting the system of - oil circuit / radiators / pumps / fans – that assures the cooling of the oil by forced convection [4,6,7].

The power losses recovering can be made by [7,10], when the environmental conditions can allow the cooling of the PT by natural convection and radiation in the pail. In this case, instead of using forced convection cooling system, it is used a system that will transmit the surplus heat power to a consumer. This can be realized or by direct transfer of thermal energy, or through a system that assures a degree of thermal energy stocking, the actual cooling system of the PT by forced convection will be stand-by.

There are many possibilities of power losses recovering, the most adaptable one is to use water to cool the oil, growing the temperature of the cooling water to a enough high value it may be using to other aims. The principal problem is to attain enough high temperature that allows using it for other aims. In a system that uses water to cooling the oil, the output temperature of the water will be based on water flow. Low water flow results high water temperature that leads to high oil temperature in the PT. On the other hand, a higher flow will transfer a larger amount of PT heat to the water, but the temperature of the water will be lower.

So, it is necessary to make compromise between the exhausted heat and the temperature in the inside of the PT, on the other hand, and the cooling water temperature at the output of system. The water between (60 – 70) °C, has multiple utilise.

In the PT the released heat recovery problem is important, taking into account that the yearly energy losses in the transport and distribution networks gives near 1300 TWh, 61 mild. $ and above 700 mil. tones of green house gases. [17]. The concern falls in the EU energy strategy engaged to grow its efficiency until 2020 with 20%. This means, that PTs are considered as one of key products, because the corresponding energy losses of 4,6 million units installed in Europe, representing 33 TWh / yr. The energy economy potential associated to PT in whole of the world is considerable.

The EU has selected PTs from a list of 10 products that will be regulated in the following years.

2. RECOVERY POTENTIAL OF RELEASED HEAT IN THE STUDIED PT

The object of the study was to identify and investigate some recovery solutions of power losses in electric stations (ES) of 110 kV / MV managed by SDEE Oradea. In 18 existent ES are 30 PTs with nominal power of [10, 16 şi 25] kVA [17]. The active power losses assessment of a PT is made with nominal data and operation condition of P, using the following expression:

$$\Delta W_T = \left[\left(\frac{U}{U_n}\right)^2 \Delta P_{Fn} + \lambda \frac{U}{U_n}\frac{i_{0n}}{100} S_n\right] T + p^2 \left[\Delta P_{wn} + \lambda \frac{u_{kn}}{100} S_n\right]$$

τ (1)

where: τ

(U, U_n) – effective operational voltage (U) nominal voltage (U_n);
$\beta = S / S_n$ – relative apparent power;
(S, S_n) – operational apparent power (S) and nominal apparent power (S_n);
$(\Delta P_{Fn}, \Delta P_{wn})$ – nominal real power losses in magnetic and circuit and in the windings of the PT;
(u_{kn}, i_{0n}) – relative nominal value (%) of the short circuit voltage and of no-load current;
λ - equivalent active of reactive power;

T – time when the PT is under voltage (generally equal with the duration of analyze);
τ - period of power (S) utilization.

The nominal data and the magnitude of PT operation values in period of 11 years are given in [17]. The average values accordingly to the calculated power losses of the power losses with relation (1) for the analyzed ES are given in figure 1.

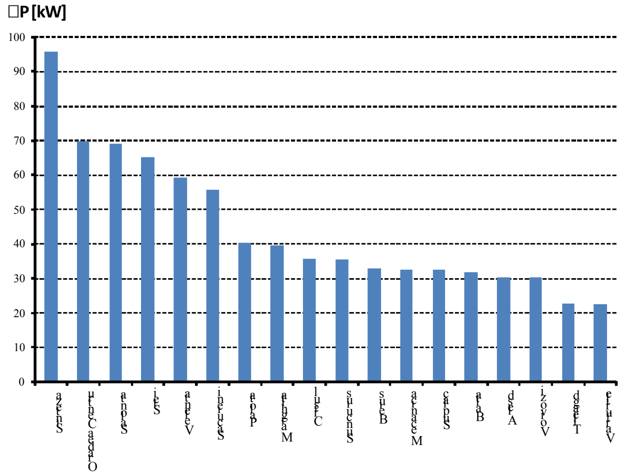

Fig.1 – Multiannual average values of real power losses in 18 ES

The losses in the PT are taken by the cooling medium (oil transformer) and are dissipated to external surface of the PT pail by convection and radiation. In function with the working regime of the studied PT and with local medium conditions, free convection and radiation isn't anymore able to make the necessary oil cooling, and the oil temperature grow. To do not exceed the optimal oil temperature are utilized installations that assure forced convection [2,3,4]. This heat flux in excess sometimes has significant values. This thermal power assures the demand of heat (in winter), of cooling (in summer) and domestic hot water for the ES buildings.

To compute the available thermal power are used established models, where exact values are introduced known from technical documentations of the PT, or average estimated values for meteorological data [17].

The computation is made by spreadsheet, as MS Excel, starting with thermal power (P) that must be evacuated from the PT, corresponding to real power losses of PT. Details about computation is given in [17].

In figure 2 are given the obtained values for available thermal power at the output of heat exchangers (cool fluid), for the analyzed 18 ES for winter, spring – autumn, summer, respectively.

For all buildings in the ES the standardized global coefficient of thermal insulation must be in range standardized values [13,15].

For the existent building types, the standardization [15] imposes for the global coefficient thermal insulation the maximum value of GN = 0,81 $W/m^3 \cdot K$.

The conventional inner temperature is considered to be t_i = 20 ^oC, [12,13]. The outside temperature is -15^oC [13].

The data of National Meteorological Agency the annual average of monthly minimal temperature for the most cool month of the year (January) is t_e= -5^oC, this value is taken in computation of thermal energy at basic load, followed by assuring the peak load by an electric resistance mounted in the buffer tank.

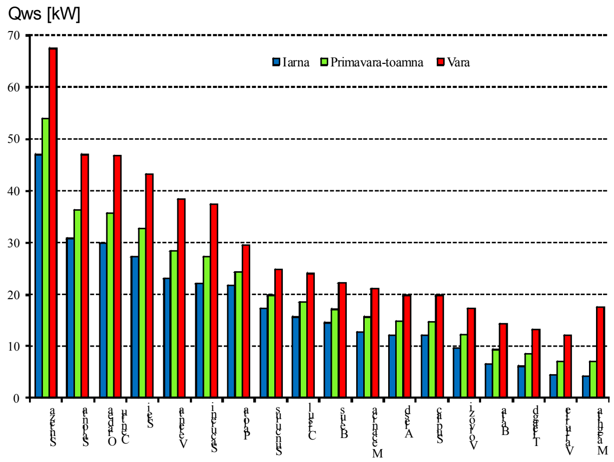

Fig. 2 – Available thermal power in ES (cumulated values) at the heat exchanger outputs

The volume of the heated building in winter, using the available heating flux, from the losses of PT, is computed by the rate of available thermal power for cooling fluid, in the heat exchanger (after preparation of domestic hot water) at the volume density of the heat flux in the building envelope:

$$V = \frac{\dot{Q}_{wc}}{GN \cdot (t_i - t_e)} \qquad (2)$$

In figure 3, are the building's volume given, that may be heated by recovered thermal power proper to real power losses of PT.

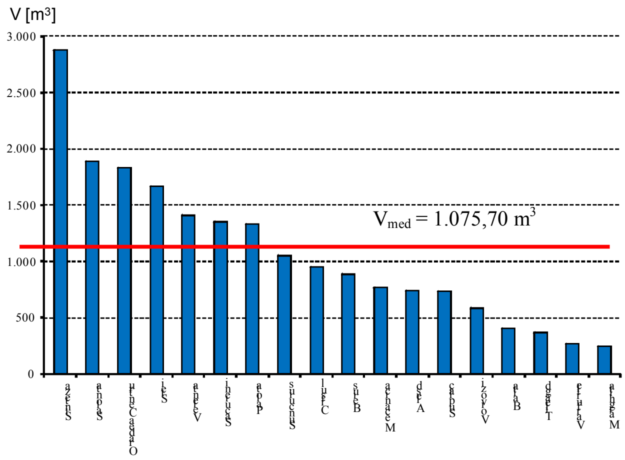

Fig. 3 –Volume of ES heated buildings

The obtained values from calculus are relatively dispersed between intervals of (250 ÷ 2.900) m^3, the average value is 1.075 m^3. Dispersion is justified by different characteristics of PT in ES, but especially, by different stress level at which the PT is supposed.

3. SOLUTIONS TO RECOVER THE THERMAL POWER IN ES

The recovery system of the power losses in PT proposed by authors of the article is detailed in the research rapport [17], uses water as thermal agent for transformer oil cooling.

From various technical recovering possibilities of power losses [3,8,10], the most adaptable is the use of water for oil cooling, growing the temperature of the cooling water to enough high value to may be used for other aims. The main problem in this sense is the difficulty to attain an enough high temperature of water that allows its use for other aims [4, 17].

A compromise must be made between the discharged heat and inner temperature of PT, and in other hand, the cooling water temperature at the output of the system.

Another problem given by this method of PT losses recovery is that for effective utilizing of hot water, is necessary that the thermal power consumer to be situated close to the source (PT).

This is justified by relative low temperature of hot water, and by reasons of reducing losses in network of hot water supply.

The system in [4,6,10], is used by air cooled PT, where air radiators have been removed, and oil circulates through an external cooling system, with a plate heat exchanger. The cooling medium is the water that takes the heat of oil, although there can be used other thermal agent, as Freon or oils.

The system has a monitoring and control subsystem, that allows monitoring and regulating water flows through the heat exchanger.

The obtained hot water is send to a tank, that make the thermal load uniform, from here is supplied the thermal energy consumers situated in the surrounding area. From the possible consumers in [xxx] is recommended the water desalination plants (if the PT is near see or ocean), distillation installations, or domestic hot water consumers in the neighbourhood of PT.

In [3] is presented a solution to recovering the heat converted losses of high power transformers and its utilization to heating domestic water or to heat industrial and residential spaces. The solution was tested, with good results at the Transformer Repairing Factory and Electric Devices from Roman, in period of 1975 – 1980.

The proposed structure by the authors of this article for the system, to recover the real power of PT is given in figure 4, as the system is detailed in [17]. As example, the studied ES has two PTs, so the system will have two plate heat exchangers situated in the PT proximity. In the circuit of the cooling water, the two heat exchangers are connected in parallel, the hot water that takes the heat from the oil, properly to the PT losses, are circulated by electric pumps with variable flux.

The hot water tank has three roles:

a) Realizes the heat exchange between cooling water of the oil of PT and supplied water in the conditioning circuit (heating, respectively cooling). This exchange is realized through a third thermal agent (usually also water) being stored in the tank;
b) The temperature of the cooling water of PT, is influenced by its load; it is possible that it doesn't attain the imposed value by the conditioning subsystem. In such situation an electric resistance is connected, so the temperature of the water has values between the imposed limits;
c) The recovered temperature is stored and delivered to the consumer, accordingly to the requirements, which mean a flattening of the thermal load.

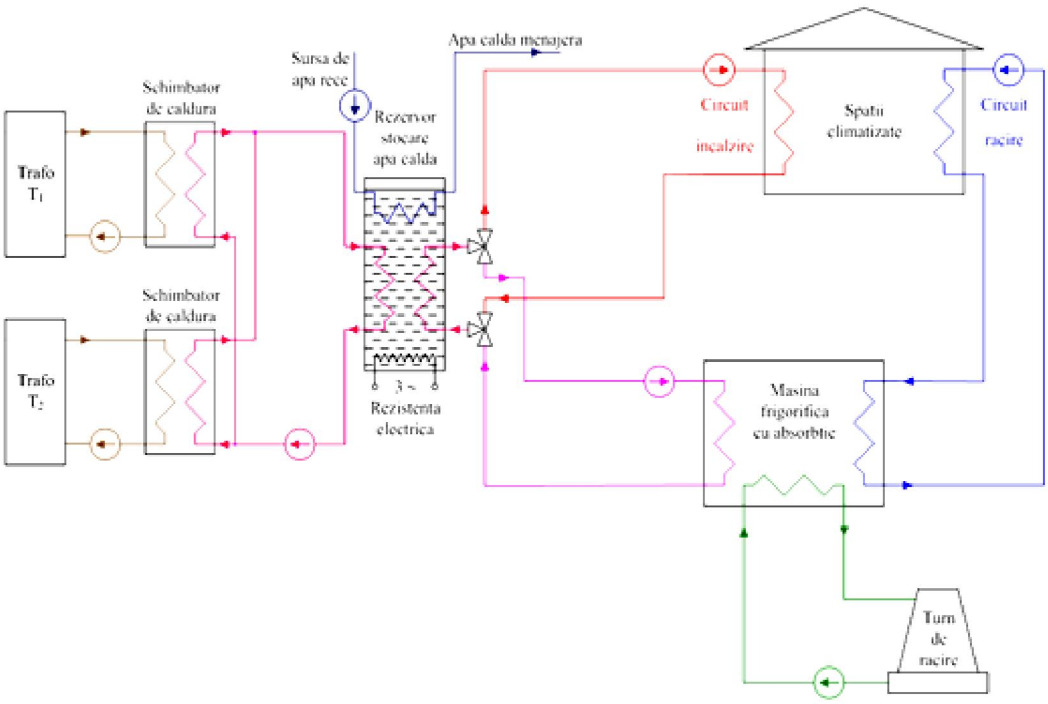

Fig. 4 Main block diagram of the losses recovering of PT and conditioning system

For this purpose, according to figure 6, is required to introduce some three ways valves (5) between the pail of PT (1) and oil radiators (2). Through these valves, the hot oil is leaded to a heat exchanger with plate from the tank, situated in neighbourhood of the PT.

The cooled oil through the three ways valve - situated on the inferior side - will return in the tank. In case of the cooling system unavailability with water, PT can be cooled by opening of the third way of the valve to / from oil radiators, so PT is cooled.

As the PT has many radiators for the oil cooling (2), the modification will refer on all radiators, realizing oil collector pipes for hot oil and also for cooled oil (fig.6), through these pipes the oil circulate to / from the heat exchanger. As it can see in figure 6, it will be used for PT only one heat exchanger, oil circulation in the cooling system is assured by the electric auctioned pump.

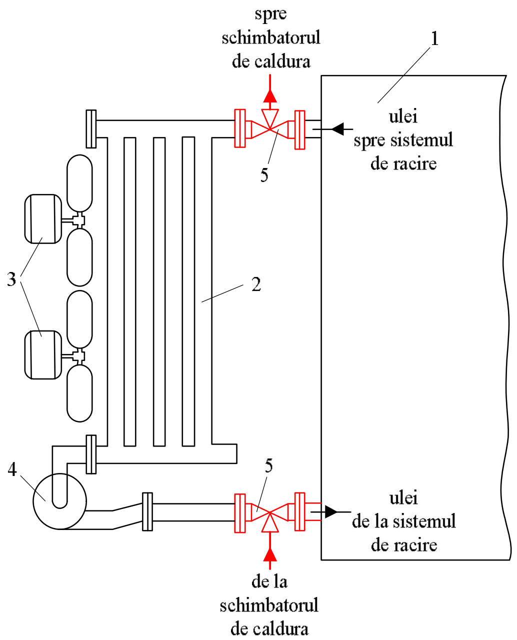

Fig. 5 – Required modification of oil cooling circuit of transformer

1 – PT; 2 – radiator for oil cooling; 3- fans for the forced cooling of radiators; 4 – circulation pump for cooling circuit of the radiator; 5 – three-ways valve

4. CASE STUDY. RECOVERY SYSTEM OF PT POWER LOSSES IN VOIVOZI ES

The ES Voivozi, has two PTs of 10 MVA and 16 MVA, operating at 110 / 20 kV. It was deduced [17], for a period of 11 years the values of amounts:

$$\Delta P_{SEmed} = 30.257\ kW$$

$\dot{Q}_{ws\ winter} = 9{,}65$ kW; $\dot{Q}_{ws\ spring\text{-}automn} = 12{,}291$ kW; $\dot{Q}_{ws\ summer} = 17{,}328$ kW

$V_{SE\ Voivozi} = 583{,}73\ m^3$

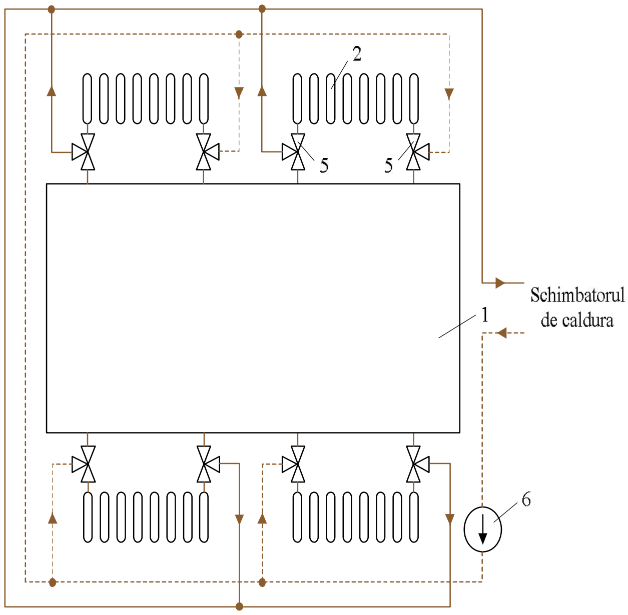

Fig. 6 – Oil cooling system scheme of transformer

1 – PT; 2 – radiator for oil cooling; 5 – three-ways valve; 6 – circulation pump for cooling circuit of the heat exchanger

The thermal power consumer, is the building of ES Voivozi, characterized in [17], where are given all information that allows the computation of required heat.

The spaces of Voivozi ES, are heated with 10 electric radiators with fans, with power of 3.700 W, which mean a total heating power of 37 kW. To prepare the domestic hot water, that is an electric tank, with a capacity of 80 l, and a power of 1500 W. The location where ES Voivozi is situated accordingly with [13, 15], is in the II climatic zone.

In [17], is given the sequence of calculations and the obtained results for the heat demand of ES Voivozi, respectively, the reasons of dimensioning and choosing the equipments for the conditioning system.

In table 1, are given a synthesis of the obtained results.

The yearly exploitation costs C_e [Eur / yr] are given by the consumed electric power by the conditioning system. On the basis of the presented characteristics the yearly electric power consumption will be:

$$W_a = (P_{MFA} + 7 \cdot P_{VC}) \cdot 8.760 + P_{RE} \cdot T_{-5} = (700 + 34 \cdot 7) \cdot 8.760 + 6.000 \cdot 410 = \quad (3)$$
$$= 10.676.880\ Wh = 10{,}677\ MWh$$

where:

P_{MFA} – consumed electric power by the refrigerating machine with absorption;

P_{VC} – electric power consumption by the fan - convector;

P_{RE} – electric power consumption by the heating rezistance of the stocking tank;

T_{-5} – annual average duration with external temperature under -5 ºC (for zone of Oradea T_{-5} = 410 ore/an).

Table 1 – Necessary investments to realizing the conditioning system of ES Voivozi

No.	Name of equipment	Quantity	Unit price [EUR]	Total price [EUR]
1	Heat exchange *Vitotrans 100*, model *3003 486*	2	600	1.200
2	Reservoir for drinking water stocking *SKL 500*	1	1.300	1.300
3	Refrigerating machine with absorbtion *SorTech ACS 08*	1	20.450	20.450
4	Fan convector *Galletti WH10*	7	500	3.500
5	Accessories (pipe lines, valves etc.)	1	2.000	2.000
6	Installation, adjustment, putting into service of the system	1	2.000	2.000
TOTAL INVESTMENT [EUR]				**30.450**

The price of electric power is $C_{en\ el}$ = 105 EUR/MWh, so the amount of the yearly expenses of exploitation will be:

$C_e = W_a \cdot C_{en\ el} = 10{,}677 \cdot 105 = 1.121$ EUR/yr (4)

The annual electric power consumption is (only for heating):

$W^0_a = 10 \cdot P_{REV} \cdot T_{10} + \dot{Q}_{acc} \cdot 8.760 = 10 \cdot 3.700 \cdot 5.640 + 193{,}75 \cdot 8.760 =$
$= 210.377.250$ Wh $= 210{,}377$ MWh (5)

where:

P_{REV} – electric power consumption by an electric radiator with fan;

$\dot{Q}_{acc}$ – average flux of heat required to obtain heat water for domestic consumption;

T_{10} – annual average duration with external temperature under10 ºC (for zone Oradea T_{10} = 5.640 hours/yr).

The value of annual exploitation costs (only for heating) with maintains the actual system is:

$C^0_e = W^0_a \cdot C_{en\ el} = 210{,}377 \cdot 105 = 22.090$ EUR/yr (6)

The feasibility indices of losses recovery system for a PT for ES Voivozi is calculated by reference of the current system, only utilized for space heating and hot water preparation obtaining the results below [9]:

- **uration of investment recovering:**

$$DR = \frac{I}{\Delta C_E - \Delta C_e} = \frac{30.450}{22.090 - 1.121} = 1{,}45\ years \quad 7$$

- **ctualized net incomes:**

$$VNA = \sum_{t=1}^{T} \frac{H_t - G_t}{(1+a)^t} = (22090 - 1.121) \cdot \sum_{t=1}^{20} (1+a)^{-t} - 30450 = 148059\,EUR \quad (8)$$

The actualized net incomes for the analyzed period – 20 years – is more above the imposed limit.

- **Indicele de profitabilitate**

$$IP = \frac{\sum_{t=1}^{T} \frac{H_t}{(1+a)^t}}{\sum_{t=1}^{T} \frac{G_t}{(1+a)^t}} = \frac{(22.090 - 1.121) \cdot \sum_{t=1}^{20} (1+a)^{-t}}{30.450} = 5{,}86 \quad (8)\ (9)$$

Where:

ΔC_E – registered economy by reducing the proper technology consume;

ΔC_e – annual costs of supplementary exploitation;

G_t – realized economic (costs) effort for t year.

As results, all indicators value show that investment is feasible.

5. CONCLUSIONS

- The average multiannual values of real power losses by the 18 PTs are in range of (22 ÷ 96) kW, the average value is 44,547 kW;
- The available thermal power for ES at the output has different values depending on environmental conditions. In this sense the calculus were made for**D** three seasons: winter, spring – autumn and summer. The values between the following range:
  - For winter: (4,2 ÷ 46,9) kW, the average value is 17,6 kW;
  - For spring – autumn (7,1 ÷ 53,9) kW, the average value is21,3 kW;
  - For summer (12,1 ÷ 67,4) kW, the average value**A** is 28,7 kW;

By the power losses recovering at the ES of Voivozi, appears an available thermal power, exploitable for air conditioning: $\dot{Q}_{ws\ winter}$ = 9,65 kW, $\dot{Q}_{ws\ spring\text{-}automn}$ = 12,291 kW respectively, $\dot{Q}_{ws\ summer}$ = 17,328 kW.

With this thermal power a volume of 583,73 m^3 can be used to air conditioning and 100 l hot water can be prepared daily at 50ºC.

The necessary heat flux used to heat the ES Voivozi buildings is $\dot{Q}_{nec} = 13{,}658\,kW$, the difference of 4 kW between the required and available power is assured by an electric rezistence of 6 kW, located in the stocking tank, that will cover the high load with temperature lower than -5°C.

The necessary investments to realize the recovery system for PT of ES Voivozi is 30.450 EUR, and the annual exploitation costs will be 1.121 EUR / yr. The actual heating system for spaces of ES Voivozi, and the system for preparing domestic hot water needs an annual cost of exploitation of 22.090 EUR, in conditions without cooling of the spaces in warm season.

The reliability indices have the following values>

- Payback time: DR = 1,45 ani;
- Actualized net incomes: VNA = 148.059 EUR;
- Profitability index: IP = 5,86.

All indices have values that rises the limits of imposed efficiencies, showing the fact that the investment is feasible.

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