Avoided CO_2 Cost. Case Study for a Conventional Power Plant

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***Abstract*—**The paper presents an analysis of a series of different strategies for the decrease of the CO_2 emissions produced by a conventional coal power plant. All the strategies were compared in terms of CO_2 emissions and the avoided CO_2 cost.

Very good results were obtained for steam turbine power plants operating in parallel with renewable energy sources. Cogeneration and trigeneration increase the energy quota of the renewable energy sources decreasing the cost of avoided CO_2.

Another interesting solution analysed here was the post-combustion carbon capture and storage (CCS). CCS has the advantage of a low cost for the avoided CO_2 cost combined with almost null CO_2 emissions. CCS also ensures a stable operation platform that would not affect the stability of the electrical grid. Lower CO_2 emissions are possible when rapid-cycle gas turbine plants are compensating renewable energy sources, but with a higher cost for the avoided CO_2.

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***Keywords*—**Parallel operation with RES, carbon capture and storage.

I. INTRODUCTION

The recent years have brought large support policies for renewable energy sources (RES) that caused a rapid increase of the installed power of these plants. The support policy implemented in Romania, includes large subsidies that are altering the market self regulatory effect, influencing the competitiveness of the conventional power plants. Another important aspect of the Romanian support policy consists in the priority for renewable energy sources to the electrical grid. These particular conditions tend to gradually eliminate the conventional power plants as new plants based on renewable energies are constructed.

On the other hand the high costs determined the producers to avoid the investment in energy storage systems for the compensation of the renewable energy sources. The operation of the energy system is possible due to the hydro power plants that ensure around 30 % of the total electrical energy demand

However the situation will change, with an important decrease of the subsidies in the near future. The operation under these new conditions will implicate new relations between the main actors of the energy market.

A possible evolution of the actual situation might necessitate a parallel operation of conventional and steam and gas turbines power plants and renewable energy sources.

In order to highlight the integration of the renewable energy sources all the calculation were made in relation with the quota of the electricity produced by these sources:

$$f_r = \frac{E_r}{E_s} \tag{1}$$

E_r - The electrical energy provided by RES;

E_s - The electrical energy generated by the conventional power plant;

The avoided CO_2 cost allows an evaluation of the economical implications for the analysed scenarios:

$$Av_{CO_2} = \frac{\Delta C}{TCO_2} \tag{2}$$

ΔC - The total cost for CO_2 emissions reduction;

TCO_2 - The CO_2 emissions.

II. THE PARALLEL OPERATION OF STEAM TURBINES POWER PLANTS USING COAL AS FUEL AND RES

The parallel operation of coal power plants and RES is relatively difficult due to the slow response of the conventional plants. However this type of operation could be facilitated by the use of hydro power plants or energy storage systems that act as a buffer for the compensation of slow ramp rates of the coal plants (usually 4..5 MW/min).

If a photovoltaic power plant operates in parallel with a conventional plant, the energy storage system is mandatory, but even in this case the presence of the back-up conventional plant lowers the storage capacity, thus lowering the overall cost.

In order to compensate the fluctuating power of the RES, the conventional power plants must operate for long periods of time at partial loads.

Figure 1 presents the operation of a 315 MW group using coal as fuel in parallel with a wind farm.

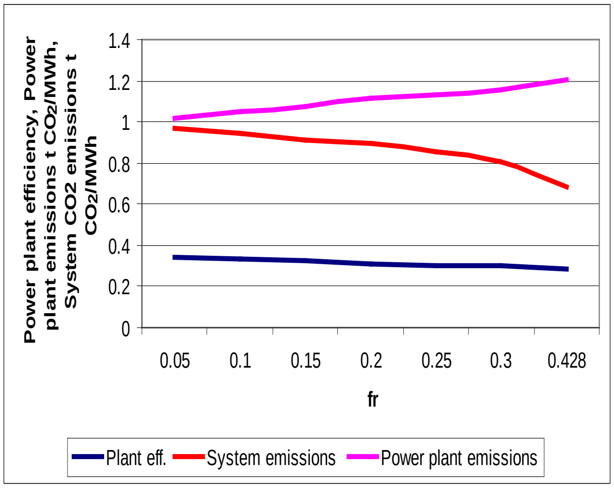

Fig. 1 The operation of the analysed system today

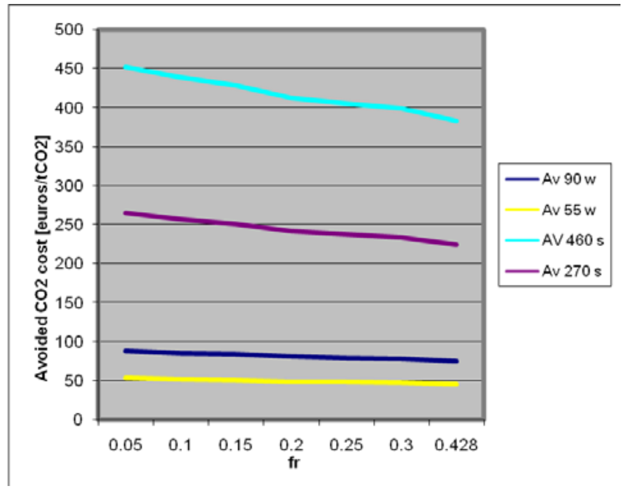

Fig. 2 Steam turbine power plant operating in parallel with RES

This operation mode is also damaging for the steam turbine power plant decreasing its life span and increasing the cost of the energy generated by the steam turbine power plant due to the partial load operation.

The graph (fig. 1) shows that the maximum power quota of the wind turbines (fr=0.42) is conditioned by the minimum operational power of the conventional power plant's group (180 MW). The quota of the wind turbines power will decrease with overall system power demand.

The graph also shows that the integration of the RES decreases the entire system CO_2 emissions. In this case, even if the partial load operation of the conventional plant decreases its efficiency (and therefore increases the plant CO_2 emissions), the overall emissions for the entire system (steam turbine power plant – RES) are decreasing.

In this case the avoided CO_2 cost has two important components:

One caused by an increase of the fuel cost quota in the overall electrical energy cost of the conventional plant caused by an important decrease of the efficiency at partial load operation;

The second component strictly related to the cost of the electrical energy produced by the RES.

For the period 2008 – 2013 Romania had a strong RES support policy that lead an important increase of the installed power of wind farms (today 22 % of the electrical energy peak demand).

Gradually the subsidies have decreased so the cost of electrical energy generated by wind farms became lower 90..95 €/MWh.

Because the investment costs for new power plants are decreasing, the calculations were performed for the EU estimated evolution of the production costs [3], that is 55..90 €/MWh for on-shore wind farms and 270 ..460 €/MWh for photovoltaic power plants.

In the past, the analysed power plant provided heat to a series of greenhouses situated in its vicinity. Due to the past operation as a combined heat and power plant there are 5 peak boilers still operational.

In order to operate again as a CHP plant, a supplementary investment is necessary in order to construct a heat network that connects the plant with the district heating system of one neighbourhood of our city. The total investment cost for the construction of the new heat network and the rehabilitation of the thermal substations that are operating now in the district heating system of the neighbourhood was estimated at 16 000 000 €.

The use of steam extraction turbines in combined heat and power groups would allow a further increase of the electrical energy quota produced by renewable energy sources. The link between the generated power and the heat output for the steam extraction turbines, might be used to increase the flexibility of the power supply of the conventional power plants. The condition is the use of oversized peak boilers that might provide the entire heat demand of the consumers (not only the peak load).

The use of oversized peak boilers is somehow common practice for many combined heat and plants, because in this way the plants might provide heat to the consumers when a malfunction occurs.

By increasing the quota of the heat produced by the peak boilers or by using exclusively its peak boilers, the plant increases its power by shifting from cogeneration to separate production of electricity and heat.

The superior efficiency of cogeneration combined with the increased quota of the wind farm leads to an important decrease of the CO_2 emissions (fig. 3).

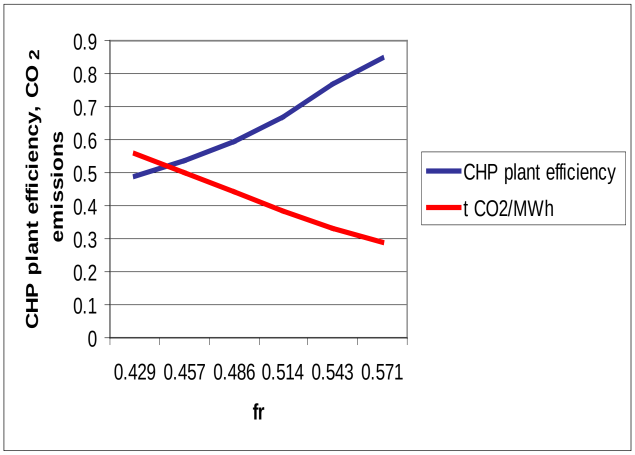

Fig. 3 CHP plant operating in parallel with a wind farm

The use of CHP plants in parallel with RES extends the power reserve of the system (CHP plant – wind farm). Due to cogeneration the lowest limit for the conventional plant power decreases from 180 MW to 132 MW. This allows an increase for the electrical energy quota of the RES to 0.57 (from 0.429 for the previous case).

Trigeneration is particularly important when operating in parallel with wind farms because during the summer the wind farms have a smaller output that coincides with a smaller output of the hydro plants caused by draught [5].

These positive effects lead to smaller values for the avoided CO_2 cost.

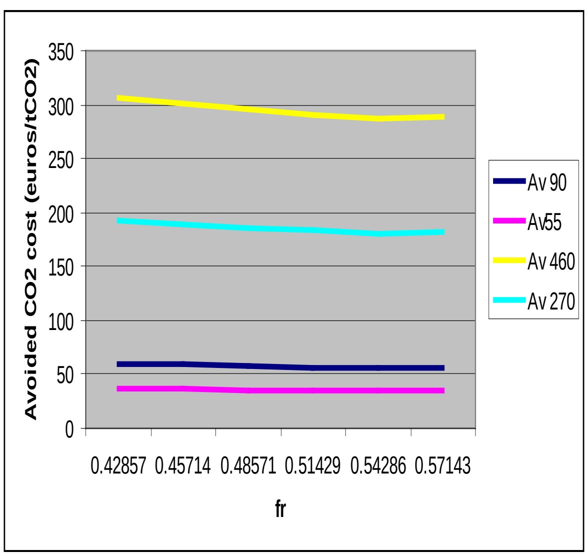

Fig. 4 Avoided CO_2 cost for the CHP plant operating in parallel with RES

III. The use of gas turbine power plants in parallel with RES

In order to operate in parallel with renewable energy sources the conventional plants have to increase their operational flexibility.

The steam turbine power plants have two major disadvantages when operating in parallel with renewable energy sources:

A modest ramp rate: 4-8 MW/min;

A slow start-up.

Due to these drawbacks, it could be advantageous to use fast start gas turbine power plants if the quota of the electrical energy generated by renewable energy sources increases to much.

Even if the performances of the old gas turbine weren't that convincing (ramps around 10 MW/min), all major producers have proposed new and upgraded versions that allow fast start-up times (10-15 min) and high ramp rates (13-15 MW/min) [1,2].

Next figure presents a scenario where the two steam turbine groups are being replaced by 3 rapid cycle gas turbine groups. In this scenario the gas turbines have a continuous operation.

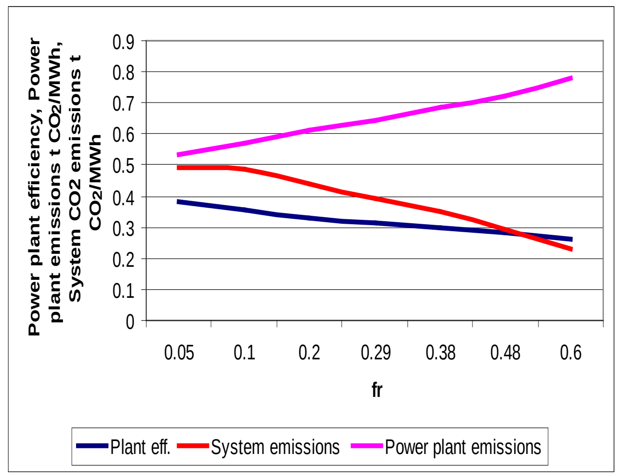

Fig. 5 Continuous operation of the gas turbine power plant in parallel with RES

Two observations emerge from the figure 5:

- A decrease of the CO_2 emissions caused by the use of natural gas as fuel;

- A higher quota the electrical energy generated by the renewable energy sources.

However the values for the avoided CO_2 cost are higher than in the previous case. .

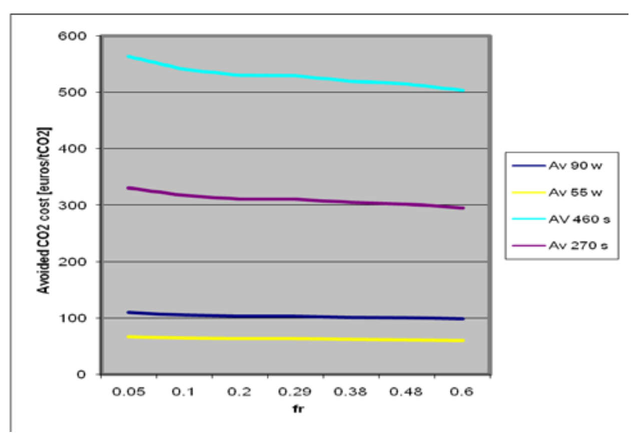

Fig. 5 Avoided CO_2 cost for a gas turbine power plant operating in parallel with RES

Cogeneration would lower the emissions and the cost for the avoided CO_2, but the presence of the HRSG would decrease the ramp rate of the plant.

The fast start-up of the gas turbines allows a further increase of the renewable energy sources power quota, because it can be stopped for long periods of time, allowing RES to provide the entire energy demanded by the consumers.

Figure 6 presents the CO_2 emissions for the “intermittent” operation of the gas turbine power plant.

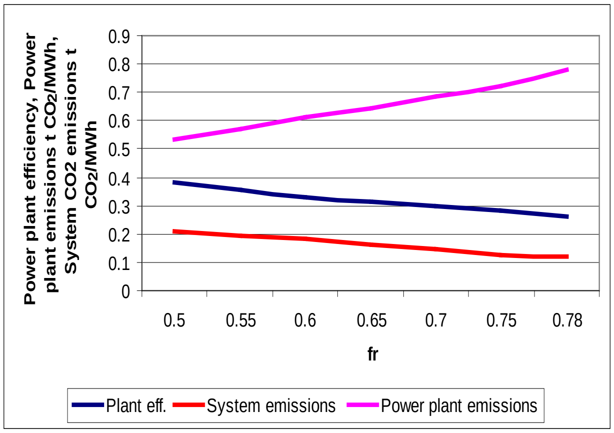

Fig. 6 Intermittent operation of the gas turbine power plant

The CO_2 emissions are in this case as low as 0.1..0.2 tCO_2/MWh. The problem resides in the steep increase of the energy price caused by the gas turbine power plant small number of operation hours. This price increase is caused by the raise of annuities and personnel costs for each year of the pay-back period with the reduction of the operating hours.

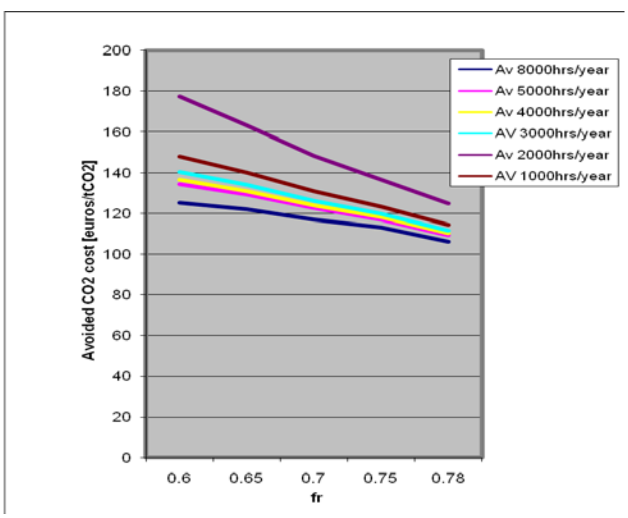

Fig. 7 The avoided CO_2 cost and the annual operation hours of the gas turbine power plant in parallel with a wind farm

The calculations from fig. 6 were performed considering the group operating in parallel with a wind farm that produces electrical energy at 90 €/MWh.

IV. Carbon Capture and Storage (CCS)

Even if there are several CCS methods available, post-combustion carbon capture was preferred for the study since the coal power plant is in close vicinity to a depleted oil field. Furthermore the analysis was focused on Alstom´s Chilled Ammonia Technology since this method is already used for another project about to be implemented in Romania [7].

For the anlaysis, the CO_2 capture and storage has two significant effects over the economical indicators of the power plant:

- important investment costs;
- an important decrease of available power of the plant caused by the operation of the CCS system.

Figure shows the CO_2 emissions for various CCS efficiencies and the reduction of the power plant’s efficiency caused by the energy consumption for carbon capture and storage.

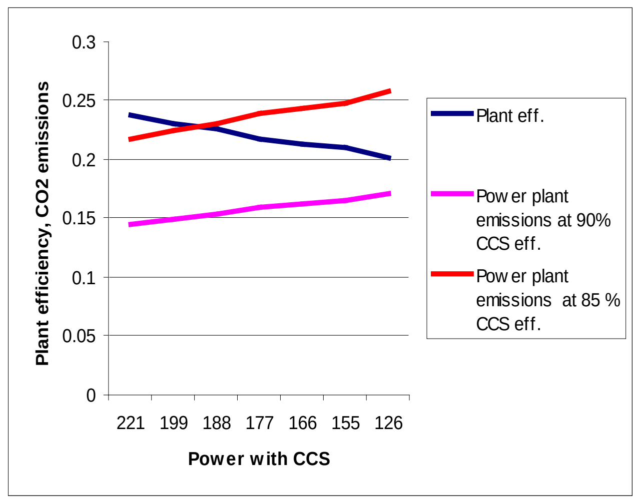

Fig. 8 Power plant emissions with CCS

The electrical energy price increases with the energy consumption for the CO_2 transport and the investment cost for the CCS implementation.

For the analysis of the avoided CO_2 cost (fig. 9) there were considered two scenarios:

- One based on rigorous calculation of the costs and their comparison with similar projects [7,8];

- A second estimation with higher CO_2 transport costs for an increased reliability of the system;

The results are comparable, in terms of CO_2 emissions with the intermittent operation of gas turbine plants in parallel with RES, but with a very low avoided CO_2 cost. Also the solution leads to a perfectly stable platform that might operate independently, without energy storage systems.

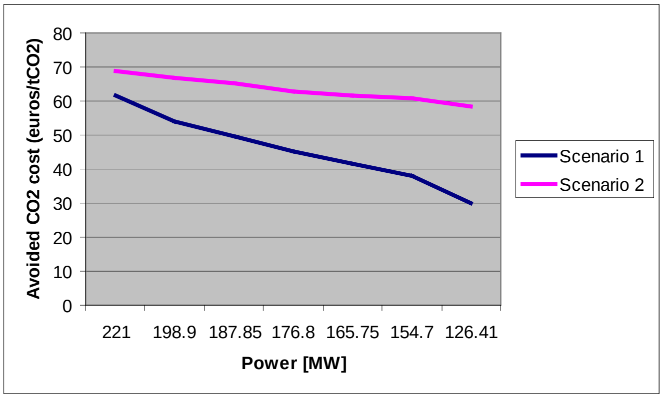

Fig. 9 Avoided CO_2 cost for an 85 % CCS efficiency

V. Conclusion

The paper highlights the importance of estimating a quota for the electrical energy generated by renewable energy sources in the energy mix, so that the conventional plants might have a continuous operation even at partial loads. In this way it is possible to maintain the avoided CO_2 cost at reasonable values.

The use of coal power plants in parallel with RES has the advantage of a low avoided CO_2 cost,

Cogeneration and even more trigeneration increase the fraction of the total power that might be generated by RES for a certain consumers demand.

The avoided CO_2 cost is slightly higher for gas turbines power plants operating in parallel with RES, if the conventional power plants have a continuous operation. However if the gas turbine power plant is operating for small periods of time the avoided CO_2 cost increases rapidly.

The fast start-up, rapid cycle gas turbines power plants might represent a safe option if RES have guaranteed grid priority through the support policy. In this case when the minimum technological operation limit is surpassed the coal power plants have to be closed down while the fast start-up gas turbine power plants might be used as back-up power plants for the energy system.

CCS definitely represents an interesting cost-effective alternative for lowering the CO_2 emissions of a conventional power plant. Compared with the other solutions analysed here, CCS has also the advantage of a stable power supply that might reach the demand regardless the environmental conditions.

The developments brought by these last years showed that there are solutions for a significant reduction of the CO_2 emissions. What is important right now is to select the solutions that ensure a sustainable cost for the avoided CO_2.

References

[1] Andreas Pickard "The Future Role of Fossil Power Generation", www.energy.**siemens**.com

[2] Bernard Tripod, Klaus Doebbeling, Christof Pfeiffer, Rudolf Heimerl "Increasing Power Generation Efficiency in Russia and CIS Countries through Further Development of the Alstom GT13E2 Gas Turbine Russia Power in Moscow, Russia", 05-07 March 2012

[1] Joan Canton and Åsa Johannesson Lindén "Support schemes for renewable electricity in the EU", Economic Papers 408| April 2010, ec.europa.eu/economy_finance/publication

[2] Anke Herold "Comparison of CO_2 emission factors for fuels used in Greenhouse Gas Inventories and consequences for monitoring and reporting under the EC emissions trading scheme" ETC/ACC Technical Paper 2003/10

[3] Liviu Ruieneanu and Mihai Paul Mircea "Adapting the regimes of trigeneration systems to the renewable energy sources integration", ECOS 2012, Perugia, Italy, 2012;

[4] Liviu Ruieneanu and Mihai Paul Mircea "Parallel operation of combined heat and power plants and wind farms", ICATE 2012, Craiova, Dolj, Romania.

[5] Liviu Ruieneanu**,** Ion Mircea, Mihai Mircea and Adelaida Duinea **"**Evaluation method for the rehabilitation of district heating systems", ECOS 2011, Novi Sad, Serbia, 2011

[6] Liviu Ruieneanu "General Method for the Analysis of Cogeneration Systems" LAP Lambert Academic Publishing AG&Co KG, ISBN : 978-3-8443-2300-9, Germany, 2011

[7] "Getica CCS Demo Project" http://www.getica-ccs.ro/index.php/english

[8] "Mountaineer Commercial Scale Carbon Capture and Storage Project" http://www.globalccsinstitute.com/projects/22947

[9] Liviu Ruieneanu "Avoided CO_2 Cost for Parallel Operation of Conventional Power Plants and Renewable Energy Sources", WSEAS, Chania, Crete Island, Greece, 2013

[10] Liviu Ruieneanu, Cristian Bratu "Evaluating the Potential of Various Methods for the Rehabilitation of District Heating Systems", WSEAS, Brasov, Romania, 2013.

[11] Enache Firincă Sanda Diana, Ion Mircea "Wind Energy used to Supply a Group of Consumers" WSEAS, Brasov, Romania, 2013.

[12] Tanel Kivipd, Juhan Valtin "Regression Analysis of Time Series for Forecasting the Electricity Consumption of Small Consumers in Case of an Hourly Pricing System" WSEAS, Brasov, Romania, 2013.