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Floating tracking cooling concentrating (FTCC) systems

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***Abstract* - The photovoltaic technology is limited by costs, by the availability of spaces for photovoltaic fields and by the storage problems. The solution suggested in this work is the use of artificial basins or small lakes for installing PV floating plants with the following characteristics: a tracking system around the vertical axis, a panels cooling system achieved with water sprinklers and a set of reflectors that, by concentrating the radiation, increase the energy harvesting. We call these plants FTCC, the acronym of Floating, Tracking, Cooling, Concentrating. Additional benefits are possible using hydroelectric basins in particular when they are equipped, as often happens, with pumping facilities. In these structures, the existing pumping devices allow to store the energy produced by the FTCC avoiding energy dispersion problems and the electric grid stress. Three FTCC system solutions are presented and discussed theoretically and experimental results are also discussed. They are characterized by different levels of geometrical concentration, Cg: <1.5, ≈2 and ≈20. In particular the first two systems use flat reflectors, whereas the third one uses parabolic mirrors. An important issue that arises when these systems are designed and operated is the uniformity of irradiance on the PV surface. This can be reached by means of an effective sensing and tracking of the system taking into account the relative position of sun and reflectors, as well as the acceptance angle of the concentrators. A first plant of 200 kWp based on these concepts is completed and grid connected in Suvereto – Livorno (Li Italy); another 30 kWp pilot plant has been built nearby Pisa (Italy).**

***Index Terms — cooling, crystalline material*, photovoltaic cells, power plant.**

I. INTRODUCTION

Photovoltaic panels are emerging as a robust, efficient, distributed energy source. The costs are decreasing and this justifies the effort to improve their use and to study the possibility of building large plants.

There are still three limitations:

- The thermal drift which lowers the system efficiency by 10-15% during the summer when greater energy harvesting is possible
- The availability of spaces for photovoltaic fields
- The high cost of tracking systems that should allow a full utilization of the PV panel

An example of FTCC System is shown in Fig. 1.

The system consists of a platform with photovoltaic panels supported by a structure in polyethylene tubes. The power of a module ranges from 20 to 500 kW, depending on the dimension of the platform. Cooling of the panel is ensured by a veil of water generated by a set of irrigators located in the upper part of PV panel.

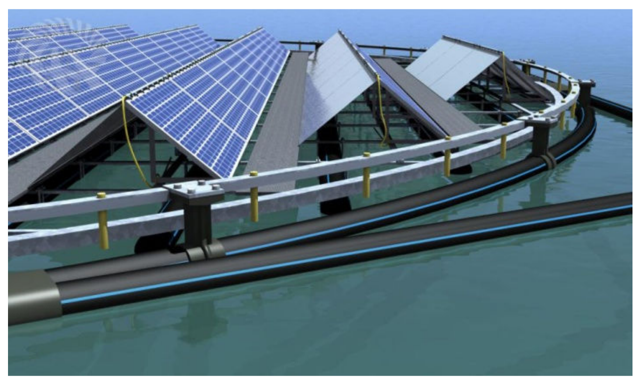

Fig. 1. Outline of an FTCC plant.

Cables and electrical parts are far from the surface of the water and adequately protected.

The FTCC system overcomes the limitations discussed above. In particular:

- Reflectors, with vertical axis tracking, increase the annual energy yield. See references 1-6.
- Thanks to the water veil PV panels stay at low temperatures with an average gain of efficiency of more than 15% yearly. See references [7],[8],[9].
- The floating platform structure allows an efficient one axis tracking, so that the system is suitable for positioning reflectors and for increasing radiation on the panels.
- FTCC exploits the unused areas of artificial basins and has a very limited visual impact.

II. THE REFLECTORS

Panels are equipped with reflectors; three solutions have been studied and are illustrated in the following.

A. First solution: booster reflector

The panels are inclined by an optimal angle (for example 40°) and the platform is oriented to optimize the solar radiation on the panels.
Shadows are unavoidable when the sun altitude is low but can be partially compensated by reflectors which increase the radiation when the sun is high on the horizon (see Fig. 2). The main problem in this case is the lack of homogeneity in solar radiation on the solar cells.

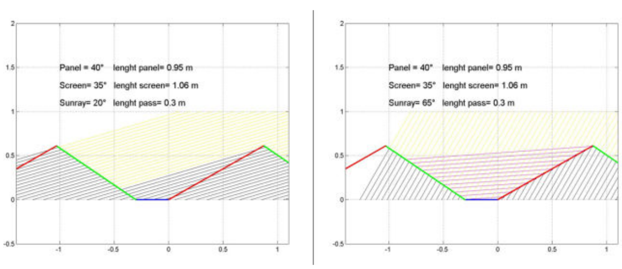

Fig .2. The shadow and reflector problem in the first solution.

Mismatch of radiation and shadows can lower the panel efficiency considerably and for this reason a large space occupied by the catwalk is left between panels and reflectors. A platform has been built using this concept and is shown in Fig 3.

Fig. 3. First solution for FTCC in Suvereto (Li). This platform has been built by Terra Moretti Holding. SIT srl is responsible for the tracking system.

B. Second solution: V-trough concentrator

In order to overcome this limit a second solution has been proposed with reflectors positioned in an inverted V shape. In this case PV panels are inclined by a small angle (2°) necessary to generate a water veil, and are oriented in line with the sun radiation.

Reflectors are positioned on the side of the panels and form a suitable angle with the horizon. In Fig. 4 the scheme of this solution is shown.
The geometrical concentration ratio depends on the reflector angle and on the correct alignment with solar radiation. In Fig. 4 the configuration with reflectors at 62° is shown. In this case the concentration factor is 2.12 and the system works correctly when the radiation angle is more than 88.4°, which implies a rather precise tracking.
The real gain due to the concentration is lower but, taking into account also panels cooling, it can reach values between 60 and 70% depending on the latitude and on the clear sky conditions.

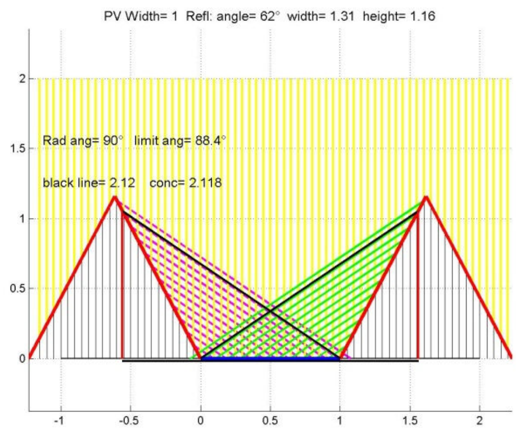

Fig. 4. Reflectors: second solution. Reflectors forming an angle of 62°. PV panel in blue, reflectors in red.

This possibility has been adopted in the pilot plant in Pisa (see Fig. 5). This pilot plant is used at present for measuring the system performance and for testing the tracking system efficiency.

Fig. 5. V-trough solution, (30° trough angle). FTCC system in Colignola –Pisa.

C. *Third solution: parabolic concentrator*

A parabolic mirror can be supported by the floating platform. A string of cells is put in the focus with a concentrator factor 20 (see Fig. 6).

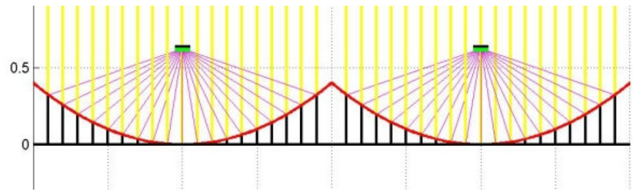

Fig. 6. Parabolic concentrator.

Water is used for the cooling on the rear of the PV cells (see Fig. 7).
This solution is in progress and will be soon operative on the Pisa plant.

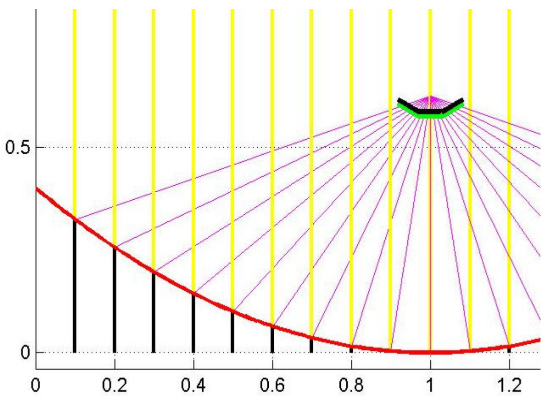

Fig. 7. Details of the PV strip in the focus of concentrator.

III. THE PLATFORM AND TRACKING SYSTEM

The platform can be of arbitrary form (circular or rectangular) and is built with modular elements (rafts) each supporting 2 or 3 PV panels (see Fig. 8). The platform is fixed trough a mooring system and rotates thanks to two motors which generate a torque around the central axis.

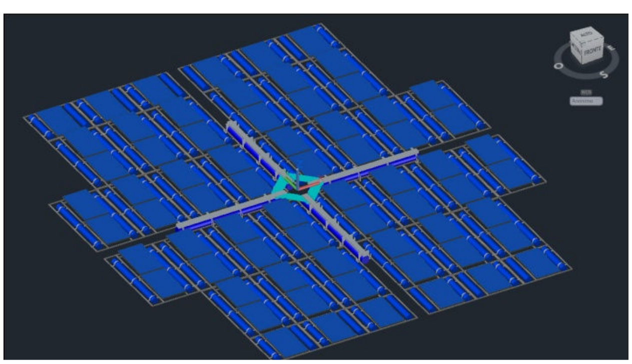

Fig. 8. Scheme of the platform

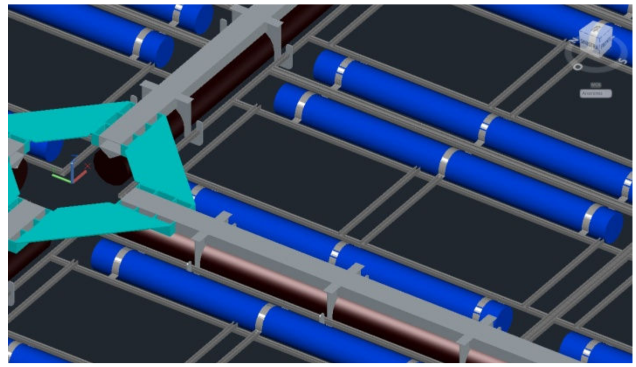

Fig. 9. Detail of the platform.

The tracking cannot be based uniquely on a geometrical algorithm (astronomical tracking). Actually the platform position is not well defined so that it is necessary to implement a solar sensor. The full system is then composed by the following parts:

1 – An electronic guidance system (EGS) able to recognize the sun position with respect to the platform: this is based on a camera and on a SW able to identify the maximum radiation zone with a precision of a few tenths of one degree.
2 – Two electric outboard motors (bow thrusters) positioned at the end of the cross
3 – A heavy stone (mooring post) with a chain that allows the platform to turn
4 – A second mooring post limiting the rotation of the platform to a certain angle in order to avoid cable twisting when the system is stopped.

The EGS, turning on and off the two motors, sets the platform in the correct direction toward the sun.
If the system is to be stopped for whatever reason (night, strong winds etc) the outer mooring post blocks the rotation of the platform over a certain angle to avoid cable twisting.
Measurement of the tracking precision has been successful and confirms the possibility to orientate the platform with a precision of 1°.
Simulations and measurement of wind load and of structure strength have been made and we have verified that the strengths involved are very low because of the system configuration.

IV. PRELIMINARY DATA ANALYSIS

The platform of Pisa-Colignola has been used as an experimental set-up for measuring gain in efficiency due to tracking, cooling and concentrators.

Whereas nothing new can be learned from one axis tracking, which increases the energy yield of about 20% as expected, important information comes from the analysis of cooling and reflector behavior.

Our experimental set-up allows to measure the power output of:

1) panels on the platform with slope 2° and without reflectors
2) panels on the platform with slope 2° + reflectors
3) panels on the platform with slope 35°
4) panels on the ground with slope 35°.

In case 1, 2 and 3 measurements have been taken with and without water veil.

PV Panels mounted on the platform are in polycrystalline silicon with a power of 235 Watt, an efficiency of 14.1 % and a thermal drift TK (MPP) = - 0,47 %/K

Some preliminary results are given in the following.

A. Albedo Effect

Albedo analysis has been performed comparing data for a south oriented panel on the platform with a 35° slope and the same put on the ground 20 meters away from the lake surface.

Results are collected in Table I and values are spread out within 3% which is the error in our measurement (taking into account PV tolerance and errors on the voltage power characteristic).

TABLE I
POWER IN WATT FOR PANEL AT 35° SOUTH ORIENTED AT MIDDAY

	02/05	11/05	14/05	15/05	16/05	17/05
Ground l	252	197	237	182	217	217
Platform	250	188	239	175	226	213
ΔP%	-0,7%	-4,7%	0,7%	-4,3%	3,9%	-1,9%

Results shows the same value (within 1%) for clear sky days and a value 5% lower for panel on the platform on partially cloudy days. These results deserve further analysis. In any case the myth of albedo lake positive effects is completely disproved.

B. Cooling

We have analyzed the cooling effects taking into account the configurations 1, 2 and 3 described above.

Results are given in Fig. 10 and show a systematic increase of power yield due to the cooling effect.

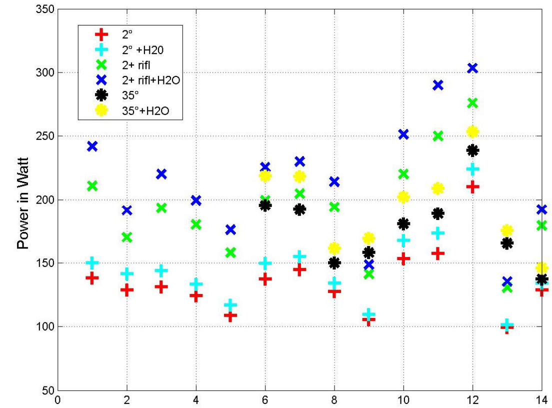

Fig. 10. Plot of power measured in May on the platform. Abscissa numerates the different data acquisitions.

Values in plot in Fig. 11 have been obtained using the relation $D\%=(W_{with\ H2O}/\ W_{without\ H2O}-1)/(T_{hot}-T_{cold})$ where T_{hot} and T_{cold} are the temperatures without and with water veil. This value gives an evaluation of the effect which is on average more than the effect of thermal drift and keeps into account also the better income impedance of radiation.

This effect has been analyzed in detail in [8]. The gain in energy conversion due to the water veil is due to the correction of thermal drift (and this effects is very important especially in sunny days) but to a good extent to the low water refraction index $n_{H2O}=1.33$. This low value reduces the reflection effects especially when radiation angle is low and this is very important in winter and in the case of radiation reflected by the concentrating system. In this case the increase in energy yield can be more than 5% and this can be seen in Fig 11 where the gain in efficiency, due to the cooling, is larger than the thermal drift correction.

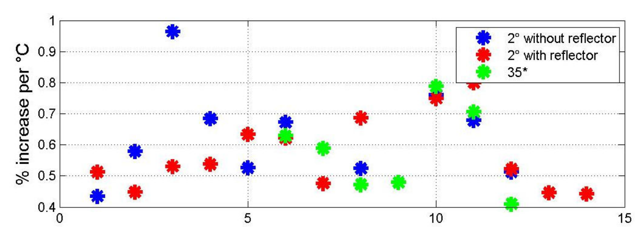

Fig. 11. Plot of increase of efficiency with water in % per °C.

C. Reflectors efficiency

The plot below shows data taken in May for a panel with reflectors compared to a panel without reflectors (without and with water).

Best values are reached in clear sky days; however interesting gains of 20-30% are obtained even in the presence of diffuse radiation.

It is worth noticing that the water veil is particularly efficient in the presence of reflectors. This is due in part to the increase in the panel temperature for the presence of reflected radiation, but mainly to the better radiation capture thanks to the graded refraction index.

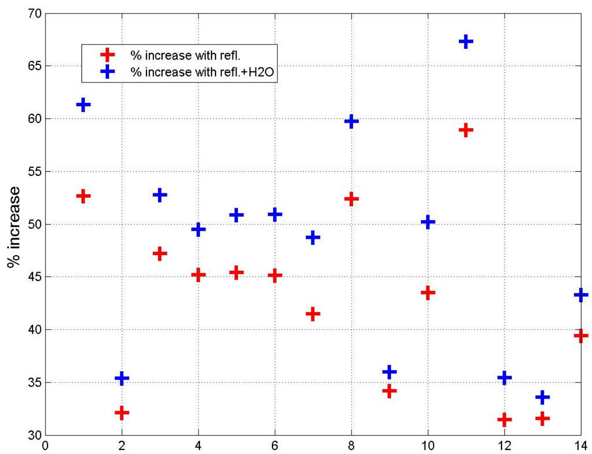

Fig. 12. Increase due to reflectors for panel with 2°. Abscissa numerates the different data acquisitions.

V. COUPLING TO HYDROELECTRIC PLANTS

Hydroelectric plants have good conversion efficiency and even if the initial fixed investment is relevant, the cost per kWh is highly competitive. The main limitation is the reduced availability since on average these plants are exploited to full power for about 1,800 hours per year.

The characteristics of these systems are exactly what is needed for an FTCC facility and the benefits that technology would gain from the FTCC coupling with hydropower are significant.

The FTCC settlement gives a sizeable increase of yearly energy produced by hydroelectric basins.

The presence of a pumping system allows to buffer energy avoiding problems in the coupling to the electric grid and reducing the costs of wiring and inverters. The daily filling of the basin, especially in summer, allows better exploitation of the pumping potential and better management of the national electric network.

In synthesis an FTCC system mounted on a hydroelectric reservoir allows to reduce costs and to improve efficiency for the following reasons:

- the existence of a basin wired and connected to the network
- the presence of a pumping system for storing the produced energy.

Finally, it should be noted that the production of photovoltaic energy is concentrated in the summer with about three months' delay compared to the maximum hydroelectric production, with a net improvement of the network optimal use.

VI. REDUCTION OF GRAY ENERGY, LIFE CYCLE AND DECOMMISSIONING.

One of the problems posed by the photovoltaic today is the high energetic cost necessary to produce PV panels. Recent estimates give a value of 5-6 MWh for the production of one silicon kWp, which suggests that the first 5 years of plant operation are spent to repay the investment made for the energy wasted in the panels' production. A solution to this problem is the use of aluminum mirror concentrators. In fact, the energy cost of aluminum is 14 kWh per kg and 15 kg of aluminum are sufficient for one kWp. Therefore the energy cost is 210 kWh, i.e. about 30 times lower than that of silicon.

On the other hand, reflectors bring down the need of silicon by a factor ranging from 2 to 10 and thus provide a strong reduction of the energetic cost of the plant.

This solution has been so far limited by the cost of tracking systems needed for plants with concentration, but the FTCC technique substantially reduces these costs and makes the plant competitive.

It must be further emphasized that the life cycle of the panel is considerably increased: the aging of the panel is mainly due to thermal stresses and these are practically zero in the solution proposed by FTCC.

Finally, our modular floating system does not require a fixed structure and the plant can be easily removed if necessary, leaving the natural environment completely intact with decommissioning costs less than one percent of the cost of the plant.

VII. CONCLUSIONS

The FTCC system proposes an innovative solution to exploit surfaces already equipped and available for industrial uses while at the same time improving the efficiency and annual yield of PV plants.

Costs of the supporting platform and of the cooling, tracking, reflector systems are comparable to those of a ground fixed plant with the advantage of an increase in the annual energy yield of over 30%.

First data support theoretical analysis. In particular cooling gives a good increase of efficiency notwithstanding data were taken in a rather cold period.

Reflectors work well but with an efficiency which is slightly less than expected (50-60% in clear sky days versus the theoretical value of 70-80%). This can be due to lack of perfect homogeneity in reflected radiation.

Tracking system gives a gain in efficiency as foreseen of about 25%. (Data are not reported in this short review but are in agreement with standard vertical axis tracking system).

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