Dynamics Photovoltaic Generators: technical aspects and economical valuation

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***Abstract*—The strategy adopted from many European nations and not, to entrust the electric energy production to differently energetic sources has determined an increment of the scientific research for the solar resource exploitation. These scientific community activities follows with attention from the entrepreneurial world have concentrated on the innovative techniques and methodologies of the source conversion, solar concentration and the direction's device optimization. This job focuses its attention on the simple application of solar-track device, based on consolidated technologies. The diffused application of these dispositive, could be, shortly, an important increment of electricity generation energy from solar source. In particular this job estimates, with economic indices and for different size of the photovoltaic systems and of the solar-track devices, the increment of electricity generation to guarantee its economically favorable for the investor.**

***Index Terms*—solar-tracker, economic analysis, implementation costs, maintenance costs, VAN, PBT.**

I. Introduction

The antropizzation processes connected to the greater production of electricity energy, have determined the permanent "impression" on our planet. It does not remain that to reduce the power consumption and entrust the power production at a balanced mix of power sources. In this context, with reference to the electricity production, the solar resource exploitation has assumed a lead role. The scientific community and the entrepreneurial world have take on various research activities on the innovative techniques and methodologies for the conversion and concentration of the solar source, and for the optimization of the device's position compared with solar radiation direction. Such researches will promote a better use of the solar source and will have a relapsing in various times. This article focuses its attention on devices of simple application, based on consolidated technologies, which the solar-track whose diffused application it could be, shortly, an important increment of energy generate from solar source. The solar-tracks are capable to move photovoltaic modules groups in order to make their plan always orthogonal to the sunbeam. Obviously, these sunbeam, have their incidence direction, on the surface's earth, variable in the space of a day and in the changing seasons. In the absence of significant barriers or special conditions of the refraction, the sunbeam direction, of the maximum radiation, coincides with the line that joins the center of the panel with the sun. Since, at the generic latitude the sun describes in the sky a hump curve, the direction of maximum radiation during the day describing a conical surface. Consequently, for an accurate tracking, the mobile plan of the solar-track must be provided with a spherical motion. The solar-track of this type are called "biaxial" and are different by the "one-axial" having only one axis of rotation. Independently by the position of the single solar axis rotation, which can be horizontal, vertical or inclined, the "one-axial" solar-track always carry out an approximate "tracking". This limits the increase of production from these solar-track in comparison to those provided of biaxial solar-track. The specific literature [1], [2], [3], [4] has often focused on comparisons between outturn of a fixed photovoltaic generator (with panels oriented and tilted to maximize the energy produced during the year) and a dynamic photovoltaic generator with one or biaxial tracking systems. In particular, most authors estimate the increase of production obtainable from use of a one-axial tracker (varying between 8% and 16% depending on the orientation of the axis and any limitations in the rotation range) and use of a biaxial tracker (which would allow production increases from 28% [1] to 40% [2], with average values, in the central-southern Italy, are around 35% [1], [2], [3], [4]). The use of trackers certainly guarantees an increase of the energy produced by photovoltaic systems, but against of an increase of their cost and of associated maintenance costs. This work aims, with an economic indicators, to determine which increased manufacturability must be assured by a tracker in order to make its use economically advantageous for the investor. This analysis is conducted for a change of peak power of the PV array and for the change of the size of the tracker scheme.

II. Solar-track Construction type

In a PV array with solar track, the modules mounted on board of the tracker are generally placed on a special panel, made with anodized aluminum with surface generally ranging from 3 to 60 m2. The solar track mechanical capacity determines the maximum number of modules installed on the its panel and consequently, changing the power's modules, it changes the electric power of the solar track. Also, the solar tracks can be classified for the number of degrees of freedom that has solar-track panel, the type of power supplied of the to the orientation mechanism, the type of movement mechanism and of the control system used to them. If the movement of the modules panel is a one degree of freedom, the solar track is defined one-axial. If the degrees of freedom are two, it is a

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biaxial tracker. The one-axial solar-track can, in turn, parted into the tilt tracker, azimuth tracker or tilted axis tracker. The fig. 1 shows a tilt tracker (with horizontal axis oriented east-west), an azimuth tracker (with vertical axis rotation provided by the installation of a rotating base) and a tilted axis tracker (with axis of rotation parallel to North-South). Thanks to the generation benefit obtained, the azimuth trackers have become more diffused [3]. The biaxial tracker are more sophisticated than one-axial; they have two servo-alignment degrees of freedom, which occurs in real time for the alignment of the perpendicular panel direction with the solar radiation accidents direction. The biaxial tracker have a spin vertical axis and a spin horizontal axis, both with its own independent mechanism for the movement. Under power supply necessary for the movement, we can divide them into electrical, hydraulic and pneumatic systems. For the most diffused realizations is preferred the electrical power supply with a few hundred watts of power engines (with direct current or most widespread with alternating current). For exceptionally large surface panel (60-100 m2) can be realized with hydraulics systems. Some systems, little used in practice, using the pneumatic supply associated with a pneumatic control based on the use of special gas [5]. Actuators that provide the movement can be of different typology. There are in the market solar track with an electromechanical actuator at rope-pulley [12], linear [11] and rotating [10], [9], [8] or hydraulic linear [10] or pneumatic linear [5]. The choice of the actuator must be made to the capacity of tracker effort (determining the number of hours of downtime due to the presence of strong winds in the installation's area [7]) and accuracy of positioning. Among the linear motion actuators, the electromechanical, are with jacks with command screw and reducers with endless screw, are widely used in industrial production, due to their simplicity and cheapness. The use of these actuators for the azimuthal motion, however, gives rise to several drawbacks such as limited angular range (always less than 180°) and the ability to stress. The rope-pulley movement mechanisms [12], gives gross pointing and complex control systems involving multiple tracker, their use is practically limited to installations on flat roofs of low dimensions. Many of the incidents described above are surpassed by the electromechanical rotary actuators with endless screw reducer [9]. This solution has an intermediate cost between linear electromechanical actuators and the pneumatic – hydraulic actuators, so that their application must be evaluated carefully the economic convenience of solar-track [12]. With reference to the control system of the radiation condition the solar tracker can be divided into systems equipped with radiation sensors and systems without this sensor (sensorless). In the first case the sensor is mounted on the PV panel and is equipped with three sensitive cells arranged on 3 sides of a tetrahedron. Whenever, under varying conditions of irradiation, the three signals of light intensity received by the three cells sensitive, will have different value, the sensor will command the solar track actuator to change the position of the PV panel to reach the condition equality. The latter called sensorless [1,11], base their operation on astronomical data stored in a special internal memory [13]. In practice, monitoring the position of the PV panel is executed in feedback loop comparing the ideal position (taken from a particular algorithm on the basis of astronomical data stored) with the position detected by transducers. The reliability of systems with sensor is strongly dependent on that of the same sensor, which, if subject to atmospheric agents that soil the three sensitive cells or if there is a high diffuse illumination component is not very reliable. For the above reasons, are now more spread the sensorless systems, for which there is a simple pre-calibration, to introduce the coordinates of the installation's location.

III. Cost of production and maintenance of dynamic and fixed solar generators

The costs of production and maintenance of a photovoltaic system with dynamics generator are certainly higher than those related to a fixed generator. The following will look at individual items of cost for construction and maintenance of photovoltaic systems with fixed and dynamic with biaxial tracker, providing them a greater increase generation.

A. *Evaluation of the production costs of photovoltaic systems with fixed and dynamic generator.*

The major cost to consider for an evaluation of the overall cost for a fixed photovoltaic generator making are the module supply, the galvanized steel support structures, the inverter and the DC panels, the cables and AC panel. Moreover, they are not ignoring the cost for the realization and transportation of concrete basements. For the evaluation of the overall cost for making a dynamic photovoltaic generator with biaxial tracker, should not be considered in relation to the previous cost items, that relating to the support structures of the modules and be added the cost items for the solar tracker and for anodized aluminum layout for placement of modules on the panel. We must also consider the surplus cost to realization the concrete basements, to hire the cranes, the lifting devices and for the transport. For both typology systems must also estimated the technical professional costs for the planning, the work management and testing and those for labor. These costs are highly variable with peak power of PV system for which you want to estimate the implementation cost and therefore cannot be evaluate in euro for kilowatt, but a lump sum. In Table 1, below, defines the values of individual cost items to be considered for an evaluation of the overall cost for the making of a fixed photovoltaic generator.

Table I
The individual items of cost necessary to evaluation the overall cost of construction of a fixed PV generator

description	value
PV modules	2.900,00 [€/kW]
Fixed steel supporting structures	400,00 [€/kW]
Inverter and protection devices for DC circuits (variabile in funzione della potenza di picco dell'impianto)	da 580,00 [€/kW] a 700,00 [€/kW]
Protection devices for AC circuits	250,00 [€/kW]
Cables	180,00 [€/kW]
Concrete basaments	30,00 [€/kW]
Transportation (variabile in funzione della potenza di picco dell'impianto)	da 50,00 [€/kW] a 70,00 [€/kW]

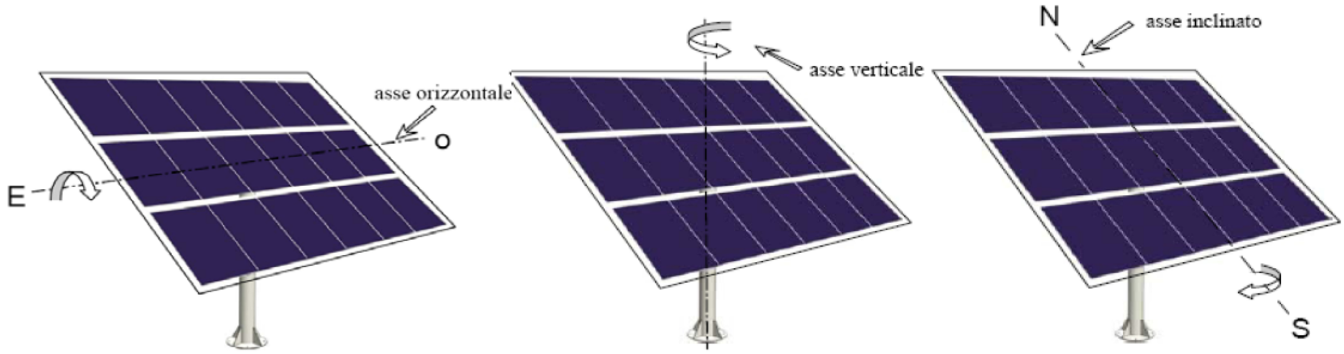

Figure 1. Tipologie di inseguitori monoassiali

The Table II shows, also, the values of the besides cost items to consider for an evaluation of the overall cost for the realization of a photovoltaic generator with dynamic biaxial tracker.

Table II
VALUES OF BESIDES COST ITEMS REQUIRED TO EVALUATE THE OVERALL COST FOR REALIZATION OF A DYNAMIC PV GENERATOR.

description	value
Biaxial solar tracker (size 4.2 kWp)	950,00 [€/kW]
Biaxial solar tracker (size 12,5 kWp)	800,00 [€/kW]
Aluminium supporting structure	60,00 [€/kW]

B. Evaluation of the maintenance costs of photovoltaic systems with fixed and dynamic generator.

Regarding maintenance costs for fixed and dynamic generators is necessary to distinguish between costs for routine maintenance and costs for exceptional maintenance. The main items to regard for a maintenance costs evaluation, of the fixed photovoltaic generator, are: the cleaning of the modules, the tightening bolts, checking electrical connections and check the functionality of the inverter. These maintenance operations are performed for different time and have an economic impact estimated at 1% of the cost of making the PV system. For these costs, always with reference to a fixed system, is necessary to add up those for exceptional maintenance. For this reason, should be taken as reference the equipment which have an average life expectancy below of the modules that is estimated conservatively equal to 20 years. In particular for the inverter can be assumed, neglect the infant mortality normally covered by the two-year warranty, a lifetime duration of 10 years. Therefore, in economic calculations that follow will be taken into account, even in this case a precaution, over 20 years, the total replacement of the park of the PV inverter. Also any overvoltage can damage some SPD, but the incidence of the replacement cost of the device is so small as not to have been taken into account. There have been also considered routine and exceptional maintenance costs associated with the steel support structure, because the thickness of zinc (about 200 µm), ensures, even in industrial environments with high humidity have a useful life more than 25 years. The same applies to the structure of a solar-tracker. Again, given that according to the environment in which the tracker is installed, the deterioration of the zinc [14][7], [6] can vary from 1 to 8 µm/year, a minimum thickness of zinc coating of 200-300 µm ensures in the worst conditions, an atmospheric agent resistance with a duration of more than 25 years. Thus, with regard to routine maintenance costs of a dynamic photovoltaic generator, besides those costs for fixed generators system, should be considered the costs for visual inspection of the tracking system and for cleaning and oiling of the mechanical movement equipment. These estimated costs for each tracker amounted to € 50.00 per year. Finally, as regards the exceptional maintenance costs of a dynamic photovoltaic generator, besides those expected for the fixed generators, to be considered the costs resulting from the presence of movement mechanical parts and electrical and electronic equipment. Indeed, the tracker actuator consists of an electric motor, of the mechanical motion transduction, of an electronic control system and a feedback loop signal position device. The electronic devices are normally susceptible to failure especially in early life (infant mortality). This situation is normally covered by manufacturer's warranty. The robustness of the three-phase asynchronous electric motors, the sealed typology, normally used for the solar-tracker movements and the slenderness of the resistant torque they encountered (consider that, in the tracker of large size, the conditions are detected by special wind anemometers and where exceed 70-80 km/h impose the positioning of the PV panel surfaces so that this does not cause wind effect) guarantee for the same MTBF (Mean Time Between Failures) of more than 10 years. In the final analysis to regard for how far in finding in the economic evaluation that follow, was considered the replacement, during the twenty years of useful life of the plant, of the 50% of the actuators mounted on the trackers.

IV. COMPARATIVE ECONOMICAL EVALUATIONS ON THE UTILIZATION OF FIXED AND DINAMIC PV GENERATORS

The evaluations reported in the following are focused on a comparative economical analysis of the building and management costs of PV systems with fixed and dinamic generators. In particular, starting from the costs analisys of the previous secrion, on the basis of some economical indexes, is calculated the surplus of producibility that must be granted by the PV system with the dynamic generator for making the investment gainful. These evaluations have been don with reference to two different sizes of the PV system (100kWp and 1MWp) and to two different sizes of the solar-track device (4,2 kW and 12,5 kW). The site chosen for the application is the city of Palermo (Italy). A PV system with a fixed generator is able to produce in Palermo yearly 1482 kwh/kWp. The yearly loss of energy production of the PV system in time has been preventively estimated equal to 1% and the life of the PV system equal to 20 year. The Energy generated from the PV system, sold in the Energy market, is payed 0,095 €/kwh (average value). Moreover all the produced energy from PV system receive in Italy a Feed-in-Tariff erogated by the GSE (Gestore Servizi Elettrici) and equal to 0,353 €/kwh (for not-integrated PVC system in 2009 according to the DM 19/02/2007).

A. 100 kWp PV system, solar-track device 4.2 kW .

In Table 3 are reported the single costs for the realization and the maintenance of a 100kWp PV system with a fixed generator. For the evaluation of the total realization and maintenance cost od a dinamic PV system with a biaxaial tracker, with respect to the listed costs in Table 3, the cost of the steel supporting structures must be neglected, and must be added instead the costs in Table 4.

Table III
SINGLE REALIZATION AND MAINTENANCE COSTS FOR A 100 KWP PV SYSTEM WITH FIXED GENERATOR.

description	value
PV modules	290000 [€]
Fixed steel supporting structures	40000 [€]
Inverter and protection devices for DC circuits	70000 [€]
Protection devices for AC circuits	25000 [€]
Cables	18000 [€]
Concrete basaments	3000 [€]
Transportation	7000 [€]
Ordinary maintenance (1% of the installation cost)	4880 [€/year]
Extraordinary maintenance	50000 [€]
Insurance for fire, lack of production and theft	2440 [€/anno]
Installation (estimation)	39000 [€]
Connection and autorization (estimation)	450 [€]
Technical costs (estimation)	15000 [€]

Table IV
SUPPLEMENTARY REALIZATION AND MAINTENANCE COSTS FOR A 100 KWP PV SYSTEM WITH DYNAMIC GENERATOR (TRACKER SIZE: 4.2 KWP)

description	value
Biaxial solar tracker (size 4.2 kWp)	95000 [€]
Aluminium supporting structure	6000 [€]
Ordinary maintenance (50€*24 trackers)	1200 [€/year]
Extraordinary maintenance (substitution of the half of the actuators = 800 € * 12)	9600 [€]
Concrete basaments (estimation)	10000 [€]
Transportation (estimation)	3000 [€]

For the evaluation of the total cost (CT), the Pay Back Time (PBT), the Net Present Value (NPV) and the rate VAN/CT, a 20 years bank loan has been considered equal to 5% of the total realization cost and a discounting rate equal to 3%. The following values have been obtained:

System with fixed generator	Sistem with dynamic generator
CT = 560140 €	CT = 628104 €

For the system with fixed generator the following values have been calculated:

- PBT = 12 years
- NPV = 624708 €
- NPV/CT = 1.12

The simulations allow one to assert that the PV system with dynamic generator assure a rate NPV/CT equal to that of the PV system with fixed generator if the surplus of generated energy is equal at lest to 17.6 %.

B. 100 kWp PV system, solar-track device 12.5 kW

Changing the tracker size, some values in Table 4 change as reported in Table 5.

Table V
SUPPLEMENTARY REALIZATION AND MAINTENANCE COSTS FOR A 100 KWP PV SYSTEM WITH DYNAMIC GENERATOR (TRACKER SIZE: 12.5 KWP)

description	value
Biaxial solar tracker (size 12.5 kWp)	80000 [€]
Ordinary maintenance (50€*8 trackers)	400 [€/year]
Extraordinary maintenance (substitution of the half of the actuators = 1000 € * 4)	4000 [€]
Concrete basements (estimation)	12000 [€]

The following values have been obtained: System with fixed generator Sistem with dynamic generator CT = 560140 € CT = 613804 € The simulations allow one to assert that the PV system with dynamic generator assure a rate NPV/CT equal to that of the PV system with fixed generator if the surplus of generated energy is equal at lest to 13.7 %.

B. 1 MWp PV system, solar-track device 4.2 kW In Table 6 are reported the single costs for the realization and the maintenance of a 1 MWp PV system with a fixed generator. With respect to the case considered in Section A, the cost for the video surveillance of the PV system has been introduced because the system is assumed installed in a unguarded place. Moreover the rent cost of the field in which the PV generator is located is considered. Finally, for the evaluation of the total realization and maintenance cost of the 1MWp dynamic generator with biaxial tracker, with respect to the costs in Table 6, the cost of the steel supporting structures must be neglected, and must be added instead the costs in Table 7.

The following values have been obtained: System with fixed generator Sistem with dynamic generator CT = 5420400 € CT = 6234400 € For the system with fixed generator the following values have been calculated: - PBT = 12 years - NPV = 6058333 € - NPV/CT = 1.12

The simulations allow one to assert that the PV system with dynamic generator assure a rate NPV/CT equal to that of the PV system with fixed generator if the surplus of generated energy is equal at lest to 16.8 %.

Table VI
SINGLE REALIZATION AND MAINTENANCE COSTS FOR A 1 MWP PV SYSTEM WITH FIXED GENERATOR.

description	value
PV modules	2900000 [€]
Fixed steel supporting structures	400000 [€]
Inverter and protection devices for DC circuits	580000 [€]
Protection devices for AC circuits	250000 [€]
Cables	180000 [€]
Concrete basaments	30000 [€]
Transportation	50000 [€]
Ordinary maintenance (1% of the installation cost)	47400 [€/year]
Extraordinary maintenance	400000 [€]
Insurance for fire, lack of production and theft	23700 [€/year]
Video Surveillance (estimation)	15000 [€/year]
Rent of the soil (estimation)	7000 [€/year]
Installation (estimation)	390000 [€]
Connection and autorization (estimation)	42000 [€]
Technical costs (estimation)	90000 [€]

Table VII
SUPPLEMENTARY REALIZATION AND MAINTENANCE COSTS FOR A 1 MWP PV SYSTEM WITH DYNAMIC GENERATOR (TRACKER SIZE: 4.2 KWP)

description	value
Biaxial solar tracker (size 4.2 kWp)	950000 [€]
Aluminium supporting structure	60000 [€]
Ordinary maintenance (50€*240 trackers)	1200 [€/year]
Extraordinary maintenance (substitution of the half of the actuators = 800 € * 120)	96000 [€]
Concrete basaments (estimation)	100000 [€]
Concrete basaments (estimation)	30000 [€]

D. 1 MWp PV system, solar-track device 12.5 kW Changing the tracker size, some values in Table 7 change as reported in Table 8. TABLE 8 – Supplementary realization and maintenance costs for a 1 MWp PV system with dynamic generator (tracker size: 12.5 kWp) Biaxial solar tracker (size 12.5 kWp) 800000 [€] Ordinary maintenance (50€*80 trackers) 4000 [€/anno] Extraordinary maintenance (substitution of the half of the actuators = 1000 € * 40) 40000 [€] Concrete basements (estimation) 120000 [€] The following values have been obtained:

System with fixed generator Sistem with dynamic generator CT = 5420400 € CT = 6091400 €

The simulations allow one to assert that the PV system with dynamic generator assure a rate NPV/CT equal to that of the PV system with fixed generator if the surplus of generated energy is equal at lest to 12.9 %. Figg. 2-7 reports the diagrams representing the cumulative cash flows for the six esamine cases.

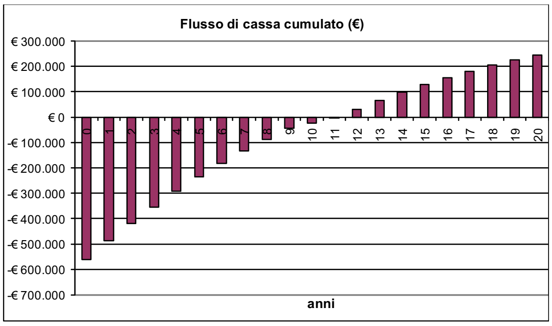

Figure 2. 7 reports the diagrams representing the cumulative cash flows for the six esamine cases.

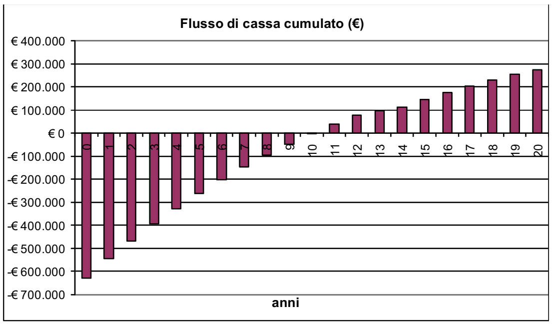

Figure 3. Cumulative cash flow for a 100 kWp PV system with dynamic generator (tracker size: 4.2kWp).

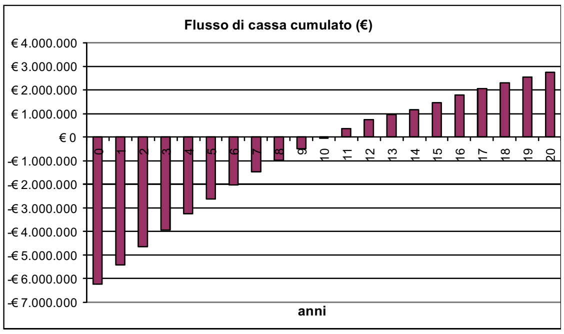

Figure 6. Cumulative cash flow for a 1 MWp PV system with dynamic generator (4.2 kWp).

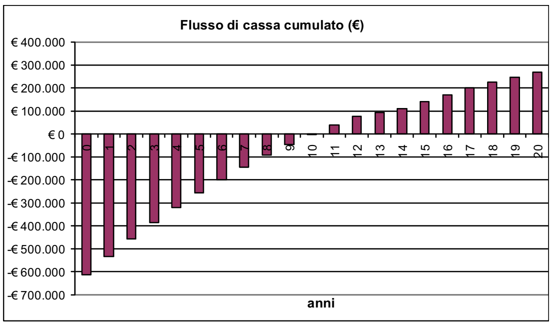

Figure 4. Cumulative cash flow for a 100 kWp PV system with dynamic generator (tracker size: 12.5kWp).

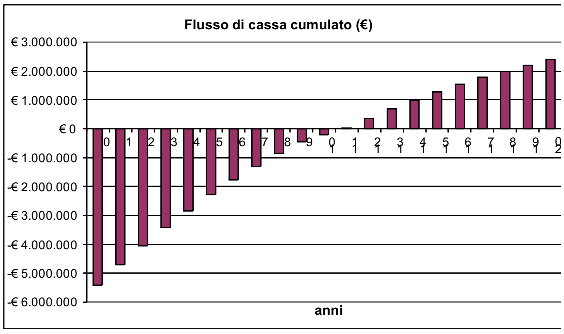

Figure 5. Cumulative cash flow for a 1 MWp PV system with fixed generator.

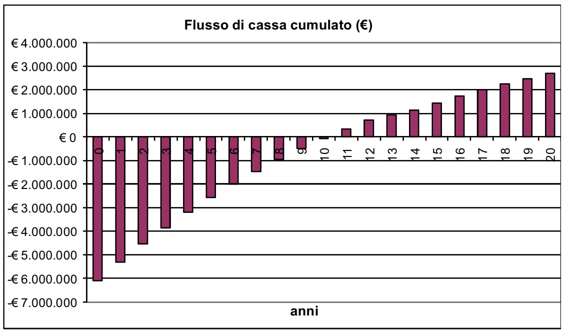

Figure 7. Cumulative cash flow for a 1 MWp PV system with dynamic generator (12.5 kWp).

V. Conclusions

Solar-trackers, in particolar the biaxial type, is able to assure a greater energy production of PV systems. With the introduction of the Feed-in tariffs support mechanism for PV systems, the energy production has become the first parameter for the evaluation of a PV generator, and so is important to verify the economical advantages of the utilization of the solar-trackers. The economical analysis and the simulations presented in this work allows one to assert, with reference to PV systems with biaxial solar-trackers, that their utilization must be preferred with respect to PV systems with fixed generator. Moreover the utilization of bigger sized solar-trackers make the investment more economical.

ACKNOWLEDGEMENT: This work has been partially supported by the EC funded project BeyWatch IST-223888. The Authors would also like to acknowledge the contribution of SDES (Sustainable Development and Energy Savings) Laboratory – University of Palermo.

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