Efficient and water-saving cleaning of the PV solar systems with TF-4 technology

I. General problems of solar systems cleaning

1. The need for cleaning the solar modules

The peaking of most oil reserves and impending climate change are critically driving the adoption of solar photovoltaic's (PV) as a sustainable renewable and eco-friendly alternative. The solar systems and large-scale solar power plants are planned by precise engineering methods. The structure of wiring for minimum loss, the inverters efficiency and the modules orientation are carefully determined. All these will help to design the most powerful operating PV systems under the given site conditions with smallest losses.

In contrast, the solar facilities operation hardly gets appropriate attention to reduce the losses in a long time. There are vulnerable to, often overlooked, on-site omnipresent practicalities such as deposition of dust, bird droppings, sand, tree leaves and salted water-stains can significantly degrade the efficiency of solar thermal installations. In recent research works and investigations revealed realize how significant performance loss caused by soiling of PV modules. Soiling accounts for dirt, snow, and other foreign matter on the surface of the PV module that prevents solar radiation from reaching the solar cells. Dirt accumulation is location - and weather- dependent.

The solar modules are increasingly soiling during their operating life causing losses in their electric power production.

Accumulation of dirt is critical as a further decrease in the system efficiency will tend to make PV systems an unattractive alternative energy source.

The solar module surface contamination is multi-factorial process. The local environment comprises site-specific factors influenced by the nature of prevailing human, industrial, agricultural activities, road transportation, built environment characteristics, natural vegetation types and weather conditions. These effects are significantly more difficult to define losses in energy production.

Despite the difficulties, the solar PV system owners and operators have fundamental interests to appreciate properly the negative impact of soiling, and on this basis to select and to use an appropriate cleaning system. This is not an insignificant matter. A variety of research studies and consistent data show that the annual electrical power loss due to the soiling of modules can be substantial.

Depending on the local reality, the values range from 5.2 to 17%. In extreme cases, higher values may occur (25%). Regular cleaning of solar modules is therefore essential. Without proper surface cleaning, solar farm's performance and the owner's profit can drop up to 15-17% in the long term.

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In extreme and very dry sandy climates where rain cleans are not or only minimally enforced, failure of panel cleaning can cause even greater losses. The solar power generating facility owner or operator can no longer be able to change any construction features, such as wire resistance, or the inverter efficiency.

However, losses due to soiling of modules can be significantly reduced by using a systematic and efficient cleaning technology. It is very important to choose the cleaning time period properly, because the intensity of soiling process in the summer is stronger. However, about two-thirds of the energy production is in this period, so the negative impact of PV modules pollution is at its peak.

2. Major sources and types of soiling

During the operation of a solar module surface is inevitably contaminated. Intensity of this process depends on several factors. A systematic review of possible sources and types of pollutants helps to choose the most suitable cleaning strategy and technology for a given place.

- **Natural sources of pollution and types of soiling:**
  - Moving sand and soil particles caused by wind;
  - Bird droppings;
  - Pollen;
  - The leaves adhering on PV module surface surface moved by the wind;
  - With Saharan sand or other materials contaminated rain.
- **Varieties of contamination coming from human activity**
  - Air pollutants coming from industrial plants (soot, etc);
  - Dust and other air pollutants caused by agricultural activities (tillage, spraying, harvesting);
  - Dust generated by dirt road traffic;
  - Pollution from road transport (rubber dust, soot, carbon black, etc.);
  - Combustion products from conventional residential heating systems.

3. Manifestations of impurities on the surface of the modules

Different forms of contamination have different effect and degree of effect on electric energy production. They tend to influence the manner and time of removal.

- **Local, patchy contamination**
  This type of contamination is caused mainly bird drops. The rate may be very important in the zone of birds are retiring. This is a critical factor to be taken into account. This is because the active surface of the solar cell modules are connected in series, a cell patch-like contamination, drastically reduces the overall electric power output of a panel.

Fig.1. Bird drop on solar module

- **The entire panel surface contaminants deposited on a cumulative basis**
  Because of diversity the pollution sources and pollutants loading surface soiling layers can be varied. A dusted PV module is shown on. Fig2.

Fig.2. A dusted PV module

Different tests showed that the size of the particle of pollutant affected to the losses. The small particle size material such as carbon black loading module surface very intensively increases the loss of energy.

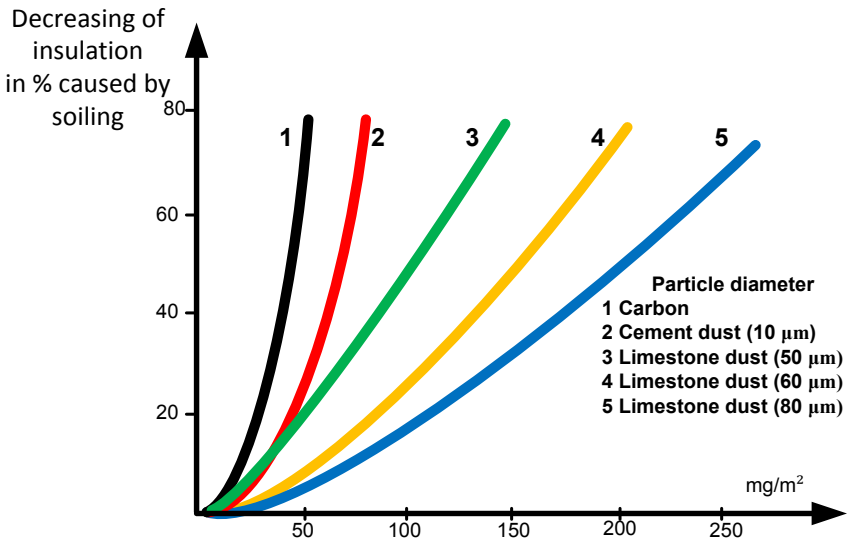

Fig.3. Effects of different particle pollutants to the energy loss

- **Accumulating dirt at the module corners**
  This form of pollution is a major source of loss. The cleansing effect of rains is not or only marginally. A small rain just washes the dirt to the bottom edges where it is accumulating (Fig.4.). To remove of these types of contamination is work and time consuming.

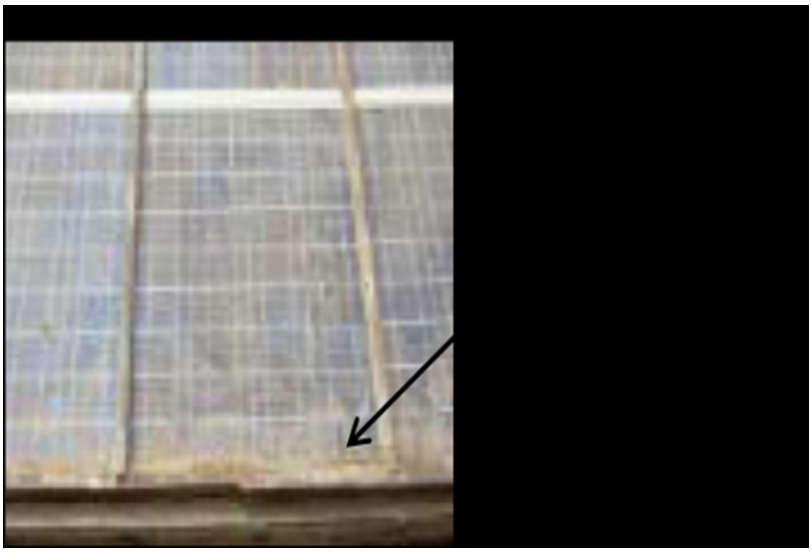

Fig.4. Accumulated contamination at the panel corners

4. Cleansing effects of rains

Cleansing effect of rains is to be considered calculating annual loss due to the contamination. However, assessing this impact is difficult. There are two important factors to be highlighted. One is the amount of rain falling at once, and the other temporal occurrence of rains.

The cleansing effect of rain in two important determinants:
• the amount of rain fell on one occasion, and
• the frequency of the rains.

• Cleaning effect of the amount of rain fallen at one time.

Significant treatment effects on the panels, thereby reducing the percentage of loss only causes a high amount of rainfall. The relationship between the loss and the amount of rain fall is illustrated on Figure 5.

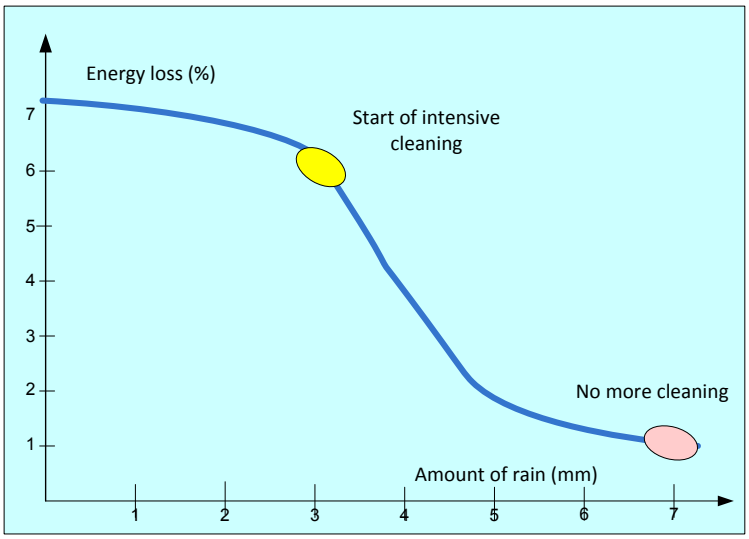

Fig.5. Curve of the rainfall cleaning effect and reducing of loss depending of volume of rain

The experience of testing is summarized as follows:

- a dirty solar panel for example - where the loss rate of 7 to 7.5% - a significant cleansing process starts from 4-5mm rain falling;
- to reduce the loss of 1-1.5% level is necessary the size of at least 7-8 mm rain;
- any rain does not result a 100% cleaning effect. (For example, the lower corners of a panel have not clarified completely).

- **The rain impact in time of occurrence**

The intensity of soiling of PV modules is the greatest usually on summer dry period. In this case, the cleansing effect of rain is minimal. As the level of radiation and hours of sunshine in the summer semester are the biggest, this is way soiling of panels caused the greatest loss in electricity generation during this period of year.

The intensity of soiling of PV modules is the greatest on summer dry period. During the summer half-year the highest power generation, and therefore the dirt during this period causes significant losses.

This is exemplified by the measurements carried out under different climatic conditions as it sowed on Figure 6.

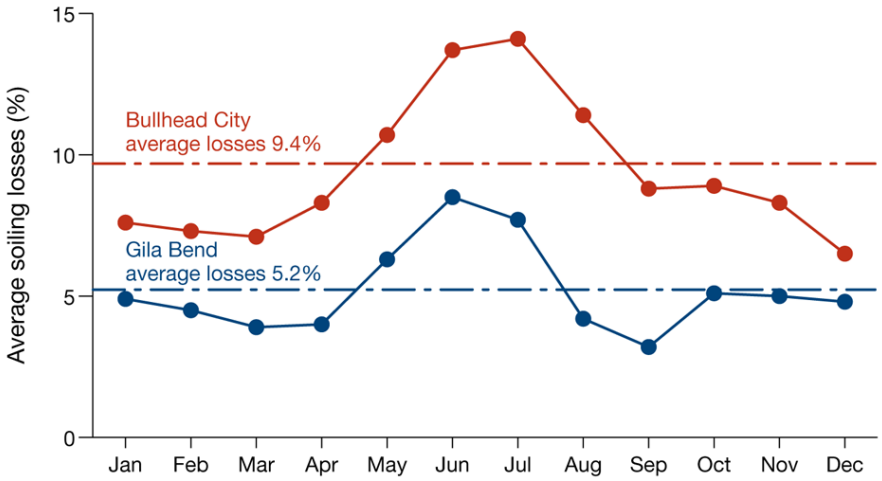

Fig.6. Changes in solar power losses due to contamination along a year.
(source: SolarPRO, 2013. Jun. / Jul.)

In summary, the amount and timing of rainfall occurrence in a calendar year hardily influence the selection of solar system cleaning strategy. If the previous year the cleaning of solar modules is canceled, the rains are less relevant treatment effect. The reason is that the dirt will burn on to the surface so that they become difficult to remove. Apart from the very rainy climate, at least one cleaning per year for PV modules is essential.

5. The effect of cleaning omission on PV modules

A rain cleans only partial. Therefore, in cases where one year no panel cleaning then in the next year the process of contamination starts already at a higher level. No cleaning on PV panels increases soiling drastically and as a consequence a very considerable energy loss happens year after year. Strongly adhering layers of soil on the surface of the panels to remove them become increasingly difficult. The treatment time and cost can be significantly increased. The mechanism is illustrated in scheme 7.

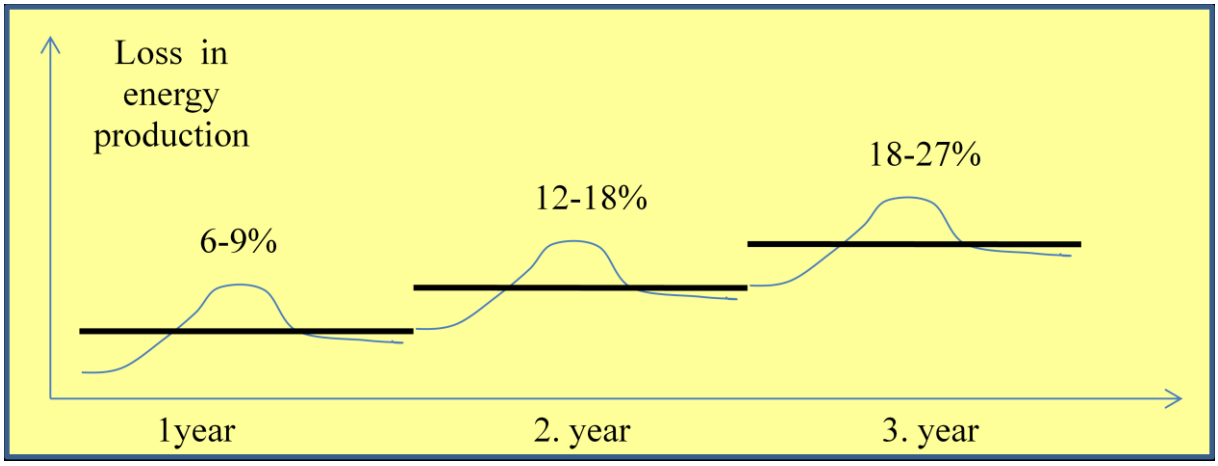

Fig.7. Non-compliance to clean the modules pollution is increasing and losses is rising

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6. Categorizing solar systems by soiling intensity

In principle must be fixed to the solar installations that cleaning strategy as well as the choice of treatment technology system always must be based on individual decisions. Because of the all situation has a side specific feature. Every individual solar system has own

- Technical and technological implementation;
- Environmental conditions in which it operates;
- Embeddings into its environment;
- Embeddings into its surrounding economy;
- A meaningful business model;
- Sources of pollutants and their effects.

Factors affecting mainly PV panels (modules) soiling offer clues about the categorization of local decisions. Selections of a good installation solution for a solar system, and its cleaning strategy, and a most appropriate cleaning technology as well as its associated business model have to base on the characteristics of the established categories.

Climatic conditions and the effects of pollution sources all contribute to and define the extent of soiling of PV modules. Therefore, the two key aspects of the categorization are

- Characteristics of climatic conditions, and
- Sources of contamination caused by pollution exposure.

Climatic conditions and the effects of pollution sources all contribute to and define the extent of soiling of PV modules.

- **The categories by climatic parameters (C)**

  C1. Temperate and humid climate
  - Annual rainfall is 800 mm or greater.
  - Precipitation is relatively evenly distributed throughout a year.

  C2. Dry summers, continental climate
  - Annual precipitation is 450-550 mm
  - The summer season is very dry.
    (For example Hungary and south part of Romania)

  C3. Extremely dry, semi-arid and desert climate
  - Annual rainfall is below 300 mm.
    (For example Iraq and Sahara)

  C4. Coastal climate
  - Annual rainfall is 800-900 mm and greater.
  - Highly salt mist with contaminants and corrosive effect.
    (For example Malta)

- **The categories by pollution intensity and frequency of cleaning needs (S)**
  - **S1. Solar system with moderate exposure to pollutants effect.**
    - The number of pollution sources and their polluting effect is small.
    - Occurring throughout the summer rains which are washing away a significant amount of soiling.
    - Cleaning up occasionally, usually it is only needed every two years.
  - **S2. Medium-intensity pollution areas**
    - The given solar system is positioned away from the sources of pollution (industrial, agricultural activities and traffic off the roads).

- Considering the partial cleaning effect of rains it is usually enough one panel cleaning process for a year.

- **S3. Areas where a solar system is subject to heavy soiling**
  - There are a lot of soiling sources near by the solar system

    (Significant industrial and agricultural activities and road traffic, migratory bird zone
  - Cleaning effect of rains is only marginally.
  - Every year one or two effective treatment is needed.
- **S4. Areas subject to extremely high contamination**
  - From multiple sources pollution impacts intensively.
  - A significant amount of soiling ingredients increase energy loss very strongly.
  - Semi-desert and arid areas with frequent sand storms. (Large amounts of sand on solar cell surfaces cause a significant performance loss. The cleaning frequency is determined by the occurrence of extreme contamination incidence)

Categories of degrees of energy loss and cleaning requirements system classification can help design and support the decision making process. The Table 1 shows classifications taking into account the two aspects together.

Table 1.

Categories by soiling intensity and climate condition				
Categories by soiling intensity	**Categories by climate**			
	K1	**K2**	**K3**	**K4**
S1	**I. loss: 2,5-4%**	**II. loss: 4-6,5%**	**II. loss: 4-6,5%**	**I. loss: 2,5-4%**
S2	**I. loss: 2,5-4%**	**III. loss: 7,5-10%**	**III. loss: 7,5-10%**	**II. loss: 4-6,5%**
S3	**II. loss: 4-6,5%**	**IV. loss: 8,5-12%**	**IV. loss: 8,5-12%**	**III. loss: 7,5-10%**
S4	**III. loss: 7,5-10%**	**V. loss: 9-14%**	**IV. loss 11-17% +**	**III. loss: 7,5-10%**
yearly losses without cleaning				

The categories express the measurement of energy losses, and also the extent to which the necessary of cleaning needs are marked Roman numbers. Already a category II of solar system installations cannot do without one annual cleaning of the modules.

At the systems categorized into groups III and IV, the solar panel cleaning is the most critical point of the effective operation. To reduce the level of losses to the acceptable level at least one cleaning operation has to be performed on the solar system each year using a state of the art technology.

The systems that fall into these groups of categories (III and IV) are mostly located in the dry climate and water-deficient areas. Therefore, for these places the cleaning technologies based on high water consumption (3.5-5 l / m²) do not come into play. However the TD-4 technology can be successfully applied, which uses only 0.06 to 0.08 liters of water per 1 m² for panel surface cleaning. That is about one sixtieth part of what the water purification technologies are using.

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Solar systems belong to the categories V and VI have extreme high pollution intensity. At least two cleaning operations are needed in these areas year after year. The TF-4 cleaning technology system can be used effectively here.

Note: High pressure water or steam cleaning technology for washing of PV panels is prohibited.

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II. Main features of the TF-4 cleaning technology

1. Brief Description of the Operation

The TF-4 cleaning technology provides an effective solution for both systems building up conventional PV modules or concentrated solar units.

Among other things the TF-4 technology has uniquely cleaning effect because its cleaning process is divided into two phases. Both of them are characterized by high productivity. The first stage is a dry, mechanical cleaning. In doing so, the panels are cleaned from easy to remove dust, sand and other dirt.

In the second phase all remaining contamination on the surface will be removed by a wet wiping process. A powerful cleaning effect is obtaining whit use a special rotating cylinder that has micro-fiber fabric on its surface. An environment-friendly mixture of water and additive is used to enhance the cleaning performance. The micro-fiber fabric wounded to the drum is constantly moved by a special mechanical structure so the surface of PV module always connects with clean fabric.

Main advantage of the TF-4 cleaning technology is minimal use of water. Depending on the degree of soiling of PV modules using only 1 liter of water could be sufficient cleaning of 12-14 m^2 surface. One can really appreciate the ultra-low water consumption if considering that the conventional water treatment technologies for the same cleaning task need 50-60 times greater amount of water.

Another advantage of the TF-4 cleaning technology is that micro-fiber textile material, after purification, can be used repeatedly.

2. Informative information about the costs of TF-4 cleaning technology application

There are a number of factors influencing the costs of solar systems cleaning. Actual cost can only be determined in full knowledge of local conditions. Each solar facility has unique characteristics. Therefore, correct decisions and price setting can be carried out only every individual situation.

While cleaning the panels would increase panel performance, the cost of cleaning would need to be accounted for in the gross outcome of the solar panel's economic benefits. There are many conditions must be met, this is just one of the efficient, productive cleaning technology. In general, the most critical factor is the price that will be paid by the electric company to the owner of the solar system for the amount of electricity produced.

The climate conditions and exposure to pollution, taking into account co-created categorization, and knowledge acquired by the current practice will allow the development of clean-up costs for specific information. The fig8 and fig9 provide a summary of cleaning price information.

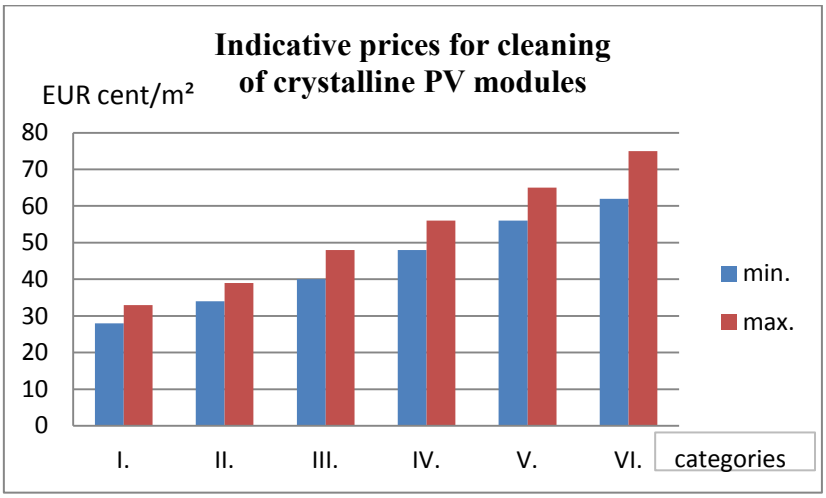

Fig.8. Indicative cleaning prices of crystalline PV modules using TF-4 technology

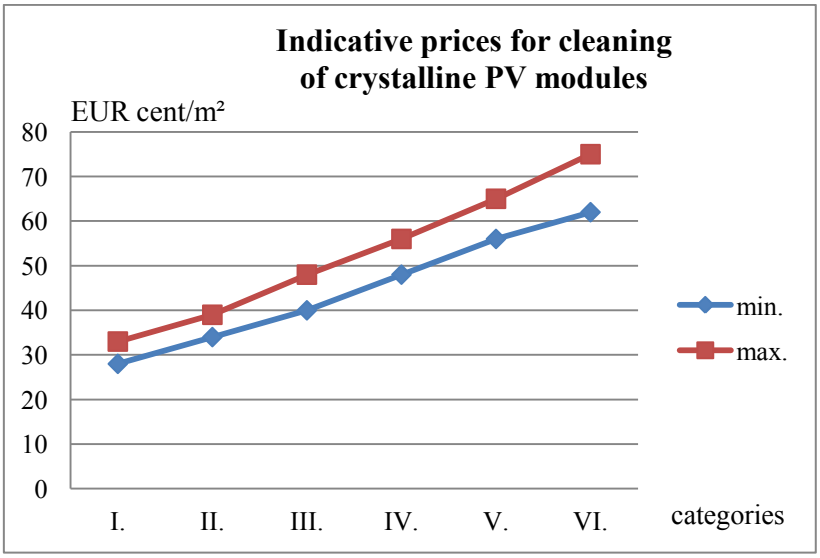

Fig.9. Differences between the minimum and maximum limits of the cleaning price Increase with the number of categories