Analysis of the Effects of El Niño in Photovoltaic Systems in Colombia

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Received: 02.11.2016 Accepted:22.12.2016

Abstract- The Colombian government has carried out different contingence plans to counter the consequences of the climatological cycle known as EL NIÑO phenomenon that began in October 2015 but still, have been reported losses in agricultural sector, forest fires, low water levels in the rivers, safe water shortage and limited generation power. This article has as objective to analyze the benefits of solar energy implementation as alternative source of generation power in affected zones by these climate changes. In order to do that, a study of the Cajicá meteorological data from 2010 to February 2016 was made, with the purpose to determine the increase factor that would have the energy generation of a solar installation during this climatological phenomenon.

Keywords EL NIÑO Phenomenon, Solar energy, solar radiation.

1. Introduction

The EL NIÑO phenomenon is a climatological event that manifests erratically each three or eight years [1]. Which consist in a pattern of unusual warming of tropical east of the Pacific Ocean, resulting in an increase in the environment temperature, a decrease of relative humidity and precipitation in the affected area[2]. For that reason, is also known as the warn phase of the meteorological phenomenon ENSO (El Nino-Southern Oscillation) which is a oscillation of meteorological parameters presented by the equatorial pacific every few years [3,4].

The current EL NIÑO phenomenon affect the country since October 2015 and it is forecast that end in April 2016, its more notable impacts are presented in departments of Andean and Caribbean regions [5,6]. The principal damage produced by this phenomenon, is the reduction of the water levels in the rivers[7]. Due to this, drought of rivers have been registered, currently affecting 7 department and 48 municipalities, this water shortage influence directly the generation power of the country, because the 70% of the Colombian energy comes from hydroelectric[8,9].

According to the above paragraph, the presidency of Colombia has increase the cost of electric energy around 1,7%, this value is assumed by hydroelectric generators and citizens, which have subsidies of 60%, 50% and 15% for strata 1, 2, and 3 respectively [10 ,11]. Another government plan for countering the consequences of EL NIÑO phenomenon is suspending the energy exportation to Venezuela and Ecuador due to the decreasing in hydroelectric energy generation of more than 46%.

These strategies are combined with campaigns to raise awareness about water and energy consumption but also are combined with a rationing plan, which consists that the principal cities in the country have a restricted horary for using electric energy, with the purpose to supply the necessary energy of the critical areas affected by the el NIÑO phenomenon [12]. In order to avoid this last resource for countering the EL NIÑO, the government are developing new projects for energy generation and in this way keep being one of the most competitive and trustworthy electric system in the world [13].

The government approved 57 new energy projects, from these 39 are in phase 1 that correspond to the pre-feasibility stage and includes an environmental impact study within its requirements. others 15 projects are in phase 2, that is the feasibility stage in which defines if the project whether it is technically, economically, financially and environmentally feasible to implement it. Finally, just 3 projects are in phase 3 with definitive designs and execution chronogram. These three projects are hydroelectric, which is the energy type most affected by the meteorological changes caused by EL NIÑO phenomenon [14].

On the other hand, from these 57 new projects just 5 are based on renewables energies and one of them is a wind power plant, that actually is in phase 1 of planning [15]. But if the government analyze the energy deficit from the renewable energies point, it is possible identify the benefits that have EL NIÑO phenomenon in the power generation through of photovoltaics and wind power installations on Colombia.[16].

These benefits are based in the different meteorological changes caused by the EL NIÑO phenomenon in the affected area such as, environment temperature increases that directly influence in the efficiency of systems based on thermal energy are presented [17,18]. On the other hand, it has more days with little cloudiness causing that the terrestrial surface receives a higher amount of global solar radiation [19].

Taking into account the previous information and knowing that the natural resources of Colombia are perfect for developing projects based on renewable energies evidence the main problem of these technologies in the country[20]. Which is that the current regulatory structure increases the difference in rentability between renewable and conventional technologies, avoiding a viable entrance to the energy market. But taking advantage of the current energy crisis caused by EL NIÑO is possible highlight the great opportunities that the renewable energies technologies have for improving the current energetic system of Colombia[21].

According with the previous, this work purposes an analysis of temperature and solar radiation variables registered from 2010 to February 2016 in Cajicá, Colombia. With the aim of characterized the behavior of these variable before and during the EL NIÑO phenomenon and identify how can affect the solar installations of the area. Obtaining as a result, the evidence of an increase in the power generation of solar installation, due to the weather changes caused by this meteorological anomaly.

2. Methodology

In order to make this article, meteorological data were collected during more than 5 years in Cajica, Colombia. From this data, the more affected variables by EL NIÑO phenomenon were selected to analyze their behavior before and during the meteorological anomaly. This behavior will compare with the power generation through a solar panel system before and during EL NIÑO phenomenon, this methodology is shown in figure 1.

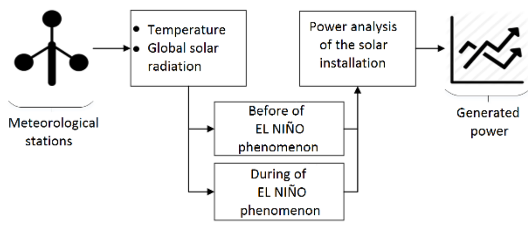

Fig. 1. Used Methodology.

2.1 Used Data

In the data collection was taken into account two meteorological stations located in Cajicá Campus of the Nueva Granada Military University, the station A is located in the latitude 4°56' 705``N and longitude: 74°0'704``W, the station B is located in the latitude: 4°56'42.198"N and longitude: 74° 0' 50.872" W.

Fig. 2. Location of meteorological stations

The meteorological stations register different variables but due to its closeness to each other as shown in figure 2, is possible obtain an average each hour of temperature, relative humidity, wind speed, precipitation and solar radiation. This data collection was made with information between January 2010 and February 2016.

From these meteorological variables, the temperature and solar radiation were selected because are the most

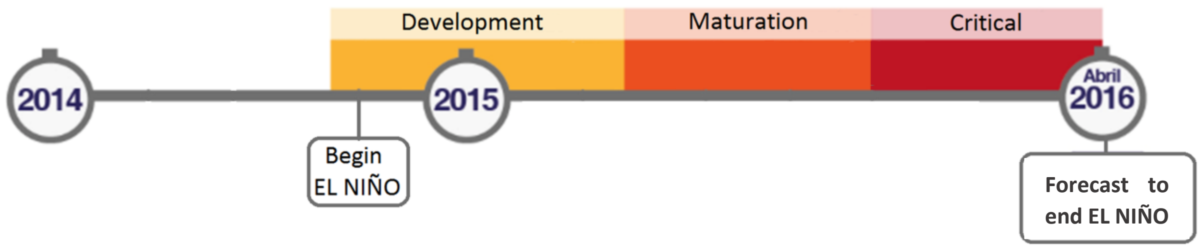

Fig. 3. Chronological order of EL NIÑO phenomenon 2015

significate factors that can affected the power generation through solar systems (Solar panels or Solar collectors).

2.2 Meteorological Data Analysis

In order to make the analysis of the data, first was necessary identify the temperature and solar radiation behavior in Cajicá for each year since 2010 to 2014. This was made with the objective of find increase or decrease patterns of these variables over these years.

For analyzing the previous variables during the warm phase of ENSO phenomenon, was necessary define the stages of itself. The current EL NIÑO phenomenon, stopped presenting normal temperatures to finals of October 2014 and it is forecast to end in April 2016.

According to figure 3, the warming process of the current EL NIÑO phenomenon had a development phase between October 2014 and March 2015, a maturation phase between April 2015 and September 2015. Currently EL NIÑO is in the most critical phase, that began in October 2015 and it forecast to go until April 2016 [22].

With these defined periods, the collected data were used to define the temperature and solar radiation behavior before and during EL NIÑO phenomenon.

2.3 Solar Power Generation Analysis

The behaviors of the previous factors were related with the generated power by an installation of 12 solar panels located between the two meteorological stations.

The solar system is composed by 12 solar panels of 300W each one and were distributed in 4 parallel branches, each branch consists in 3 solar panels connected in series. This system covers an area of 23 m^2 and have an inclination of 30º with azimut of 0º in a place without shadow, as is shown in figure 4.

Fig. 4. Solar panel installation in Cajicá.

The generated power by the solar installation is defined through the relation between global solar radiation and the efficiency of 12 solar panels of polycrystalline silicon. This efficiency is given by equation 1 [23].

$$\eta = \frac{V_{oc} I_{sc} FF}{P_{in}} \quad (1)$$

Where (V_{oc}) is the open circuit voltage, (I_{sc}) is the short circuit current and (*FF*) is the fill factor. These factors are determined by the datasheet of each panel and the maximum power (P_{max}) is obtained through equation 2[24].

$$P_{max} = V_{oc} I_{sc} FF \quad (2)$$

Finally, using the solar radiation is determined the input power (P_{in}), that refers to the solar radiation by the incident area of the 12 solar panels. Then through the efficiency is determined how much energy can generate the solar installation in one day and specific hour, with which is possible observe if the EL NIÑO phenomenon have benefits or disadvantages in power generation through solar panels.

3. Results

The analysis of the selected meteorological variables in Cajicá was divided in years, with the purpose to observe the behavior of temperature and solar radiation before and during EL NIÑO phenomenon each year.

In 2010 from January to October was manifested the cold phase of the ENSO phenomenon, prove of this is that in this period were reported frosts with temperatures between 1.47°C and 6.31°C in the dawns and temperatures between 20.11°C and 25.4°C during the day. Furthermore, the solar radiation had irradiance maximum averages of + 519.52 W/m^2 per day since January, but in the end of October were presented maximums of + 894.76 W/m^2 per day. This period is when the most critical phase EL NIÑO phenomenon of 2010-2011 was manifested, as is shown in figure 5.

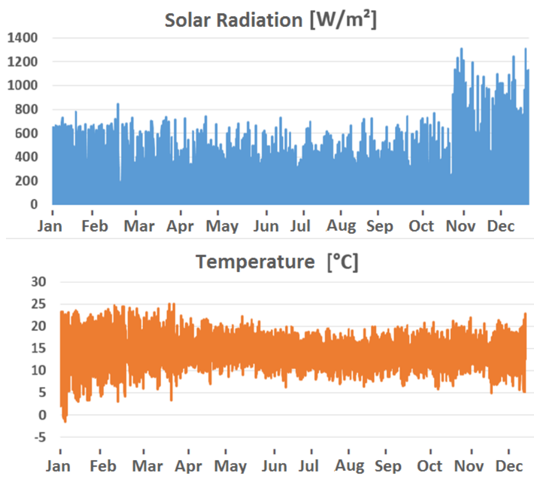

Fig. 5. Solar radiation and temperature behavior of 2010.

The El NIÑO phenomenon 2010-2011 continued until April 2011, reason why the temperature behavior in 2011 since January until the end of April presented temperatures from 10.83°C to 13.11°C in the dawns and from 17.78°C to 24.9°C during the day. While the rest of this year were registered temperatures from 3.13°C to 8.94°C in the dawns and from 16.03 to 21.17°C during the day.

For this year the solar radiation had irradiance maximum averages of $\pm$ 918.13 W/m^2 per day in the first four months of 2011 due to the EL NIÑO phenomenon, but the rest of the year were presented maximums of $\pm$ 393.65 W/m^2 per day, this value was occasioned by the beginning of LA NIÑA phenomenon or cold phase of ENSO, as is shown in figure 6.

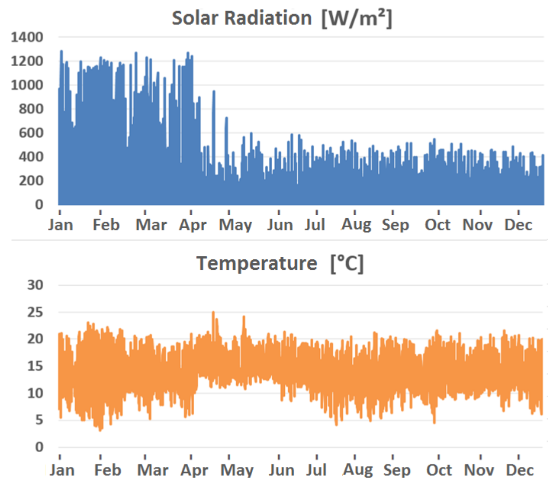

Fig. 6. Solar radiation and temperature behavior of 2011.

Figure 5 and 6 prove that during the El NIÑO phenomenon of 2010-2011 the solar radiation per square meter increased in a factor of 1,72 while the temperature increased 17.7%.

In 2012, two consequently LA NIÑA phenomena were registered, reason why during all the year had irradiance maximum averages of $\pm$ 306.37 W/m^2 per day. On the other hand, the collected data registered temperatures from 3.37°C to 7.31°C in the dawns and during the day were presented temperatures between 16.74°C and 22.27°C, as shown in figure 7.

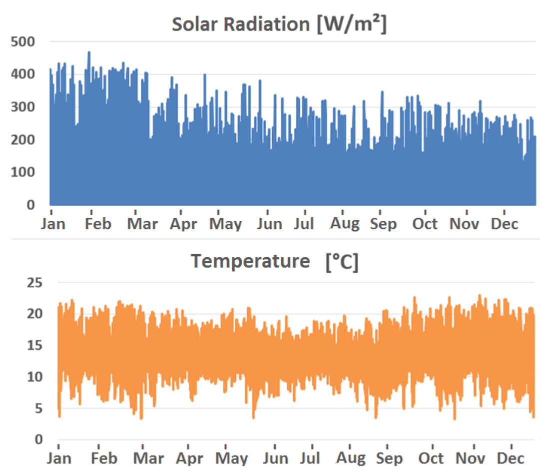

Fig. 7. Solar radiation and temperature behavior of 2012.

In 2013, the temperature behavior had an average all the year, where were presented temperatures from 3.58°C to 8.12°C in the dawns and during the day were registered temperatures between 17.08°C and 22.9°C. On the other hand, the solar radiation behavior remained an irradiance maximum averages of $\pm$ 294.37 W/m^2 per day in the first 4 months. In April finished the EL NIÑA phenomenon and began the EL

NIÑO phenomenon of 2013, This is the reason why the solar radiation had irradiance maximum averages of $\pm$ 835.43 W/m^2 per day the rest of the year, as shown in figure 8.

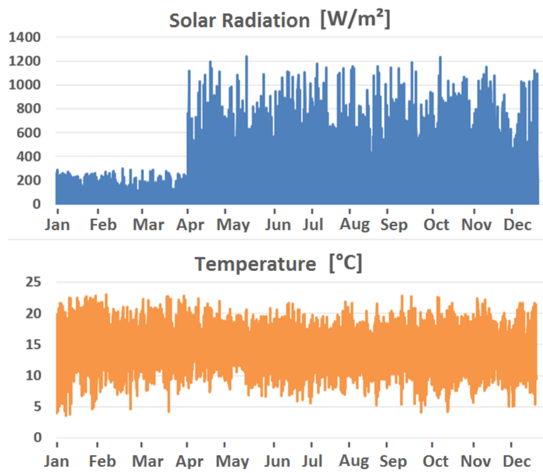

Fig. 8. Solar radiation and temperature behavior of 2013.

Due to that the EL NIÑO phenomenon of 2013 was mild, in the 3 first months of 2014 the solar radiation reported irradiance maximum averages of $\pm$ 956.92 W/m^2 per day, but once finished the EL NIÑO phenomenon the solar radiation had irradiance maximum averages of $\pm$ 520.86 W/m^2 per day for the rest of the year. On the other hand, the temperature had the same behavior of the year 2013, where the temperature in the dawns was from 2.97°C to 8.55°C and from 18.5°C to 23.47°C during the day, as shown in figure 9.

Figure 8 and 9 evidence that during the phenomenon EL NIÑO 2013 the solar radiation per square meter increased in a factor of 3,25 while the temperature just increased 8%.

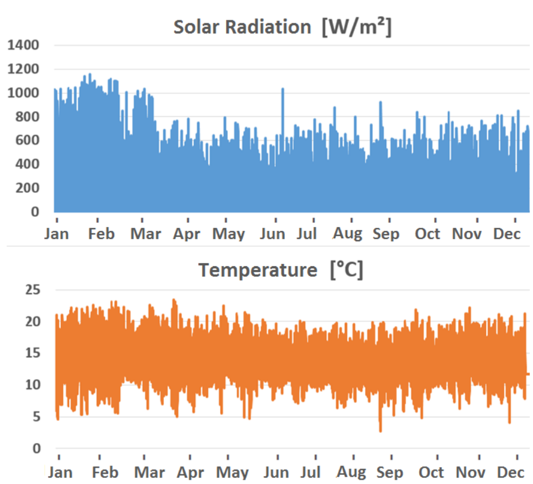

Fig. 9. Solar radiation and temperature behavior of 2014.

In the year 2015 the solar radiation still presenting irradiance maximum averages of $\pm$ 520.79 W/m^2 per day from January to end of August, but due to the new EL NIÑO phenomenon the solar radiation had irradiance maximum averages of $\pm$ 860.54 W/m^2 per day between October and December 2015. The temperature behavior for this year reported temperatures from 2.67°C to 7.64°C in the dawns and from 17.26°C to 23.2°C during the day, as shown in figure 10.

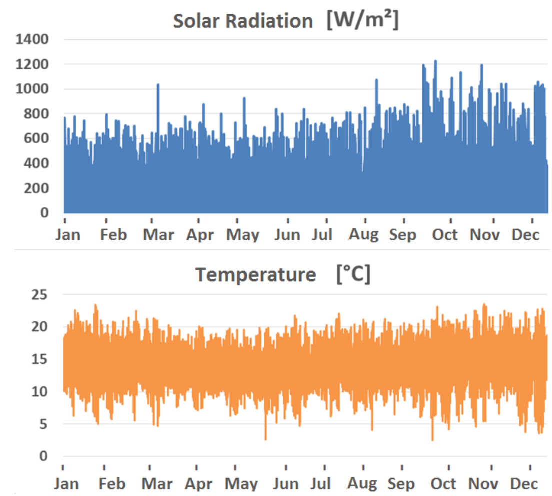

Fig. 10. Solar radiation and temperature behavior of 2015.

In 2016 it is still registering the effects of the new EL NIÑO phenomenon, reason why the months of January and February the solar radiation had irradiance maximum averages of $\pm$ 971.54 W/m^2. The temperature behavior in these two months of 2016 reported averages temperatures from 2.7°C to 9.2°C in the dawns and from 20.5°C to 25.8°C during the day, as shown in figure 11.

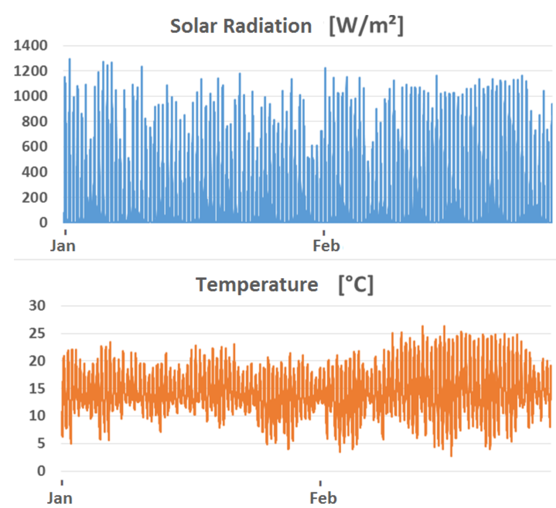

Fig. 11. Solar radiation and temperature behavior of January and February of 2016.

Figure 10 and 11 prove that during the El NIÑO phenomenon the solar radiation per square meter increased in a factor of 1.86 while the temperature increased 18.7%.

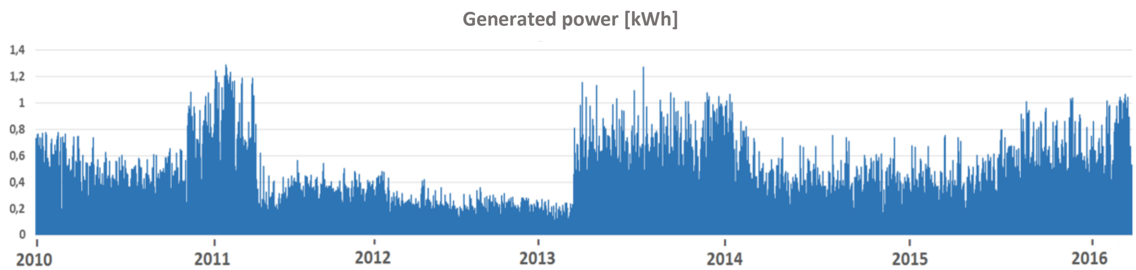

Fig. 12. Generated power by the solar installation between 2010 and 2016.

With the analyzed data, it has a solar system composed by 12 300W Canadian solar panels, which are connected in series and have a peak power of 3600 Wp in a 23.025 m^2 area. With this information was determined that the solar installation in the Cajicá campus of Nueva Granada Military University have an efficiency of 15.63% because the material of the solar panels is polycrystalline silicon.

With the efficiency of the solar installation, the information collected of solar radiation from January 2010 to February 2016 was used, for identifying the generated power by the solar installation through the different EL NIÑO phenomena.

In figure 12 is possible observe that during the EL NIÑO phenomenon of 2010-2011, the average generating power of solar installation pass from 0.49929 kWh to 0.829 kWh. Once finished this EL NIÑO phenomenon at the beginning of 2011, were presented two consequently LA NIÑA phenomena, reason for which the solar installation generated an average power of 0.268 kWh.

During the EL NIÑO phenomenon of 2013, the solar installation generated an average power of 0.8554 kWh but finishing this phenomenon the average power decreases to 0.4822 kWh. Finally, during the EL NIÑO phenomenon of 2015 the solar installation generated an average power of 0.8793 kWh

4. Conclusion

Contemplating the meteorological implications that leads the EL NIÑO phenomenon, it is possible obtain benefits of the solar radiation increasing, due to that the generated power increase in an average factor of 2.24 according with the data measured during three EL NIÑO phenomena.

Evidence of the previous information is that in the three EL NIÑO phenomena registered between 2010 and 2016, was registered that during the EL NIÑO phenomenon of 2010 the solar installation had an increase of 166.03% in the generated power. During the EL NIÑO phenomenon of 2013, an increase of 319.17% in the generated power was presented and during the EL NIÑO phenomenon of 2015 it has been presented an increase of 182.35% in the generated power.

Due to the global warming the forecasts for the futures EL NIÑO phenomena indicates that is possible that have a higher increase in the meteorological factors, which implies possible bigger impacts in the hydroelectric systems of Colombia. For that reason, the implementation of solar systems can take advantage of this same increases of meteorological factors as benefit to increase the generated power through alternative sources in the areas affected by the EL NIÑO phenomenon.

On the other hand, this information allows sizing the new solar installations that will be installed in the Campus Cajicá, with the purpose of that when in the Andean region is affected by an EL NIÑO phenomenon, the solar system can take advantage of these meteorological changes. Due to that if the system is not oversized could not duplicate the generated power, which is the principal benefit that produces the EL NIÑO phenomenon in photovoltaics systems

Acknowledgements

The authors would like to express their special gratitude to the Research Vice-chancellorship of Nueva Granada Military University

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