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Complex network approach to detect faults in photovoltaic plants: Albanian case study

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Abstract

With the trend towards photovoltaic plants in energy production, it is often difficult to describe the system status and fault conditions using traditional methods. We used machine learning and deep learning to predict PV production, but here we are focused on detecting faults in PV plants. Complex networks analysis is presented as an approach which succeeds in detecting faults in PV plants. Our case study is a photovoltaic plant installed in a factory in Albania. Firstly, we use sliding windows for different periods of time and construct a weighted directed network (functional graph) when each node represents a sensor and each edge represents the strength between the two signals which is determined by the mutual information measure. We have used in total 29 different signals from 4 different inverters for a period of six months (June 2022- December 2022). Secondly, we compute the node's strength for the signals corresponding to voltage, current and irradiance and show that when a fault occurs the weighted degree centrality of the irradiance node decreases while the voltage and current weighted degree centrality increases.

Introduction

The use of renewable energy has many potential benefits, including a reduction in greenhouse gas emissions, the diversification of energy supplies and a reduced dependency on fossil fuel markets. Based on the Eurostats statistics solar is the fast- growing energy source in Europe. Even in Albania, the capacity of PV plants has been growing exponentially over recent years. Albania has more than enough solar power projects in the pipeline to meet the 220.4 MW in the combined capacity of wind power and photovoltaic that transmission system operator OST (Transmission System of Electricity) expects to connect by 2023.

In order for the PV plants to have good performance and long lifetime it is important that the time to detect the fault and repair or substitute the faulty component is fast. These factors are related also with profitability. For that reason the case study of this paper is fault diagnosis of a 125 kW PV system which is installed on a rooftop of a factory in Tirana, Albania. The data are obtained by Fronius Solar. web database every 5 minutes for a period of six months (June 2022- July 2022).

Complex networks have been successfully used to model real-world problems and data in more than 11 areas. The idea of using complex networks as an approach for detecting faults in PV plants. In this paper, complex network analysis is used to model the sensor network described in the previous paragraph as a weighted network based on the mutual information matrix which is computed to the signals and measures the amount of information taken from one signal by knowing the outcome of the other one.

Material and Method

The data collected from the PV plant consists of 29 signals taken from 4 different inverters. Table 1 shows all the signals used in this study.

Table 1. PV plant variables for 4 inverters

Signals	Measuring unit
Active Power	W
DC Current	A
L1 AC Voltage	V
L2 AC Voltage	V
L3 AC Voltage	V
PV production	Wh
Ambient temperature	°C
Wind speed	m/s
Irradiation	W/m^2
Module temperature	°C

Figure 1 shows schematically all the steps from the time series data up to the construction of comparative time series and weighted node strength plots.

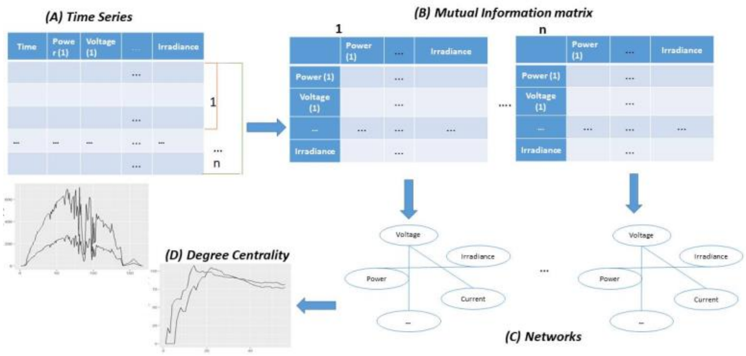


Figure 1. Weighted network construction from time series data

Firstly, considering that there are m samples and *n* different signals, the mutual information matrix with dimensions *nxn* is constructed. Each of its components gives the strength between two distinct signals. The mutual information matrix is computed for different periods of times, sliding the window from the beginning of the data up to the entire monitoring interval. The time interval used in this study is 10 hours and in total are used 125 sliding windows.

Secondly, for each of these sliding windows a directed weighted network (functional graph) is constructed [1-3]. In this paper, we are focused just on the nodes representing the DC Current, AC Voltage and Irradiation for the inverter where the fault is detected. This network is used to compute the weighted node centrality and divide the centralities in two groups corresponding to the period before and after the fault occurs.

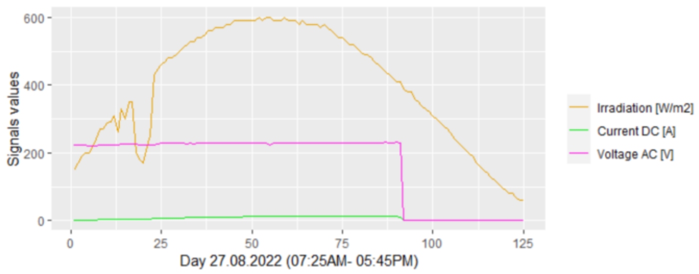
All the analysis is performed in RStudio.

Results

In this paper we have considered one fault that happened in the first inverter on 27 August 2022. The fault happened at 05:04 PM and the time interval considered is from 07:25AM up to 05:45 PM, using in total 125 sliding windows. The fault alert is “No feed in for 24 hours”.

In the first plot, we consider 0 the initial time studied (07:25) and increment by one for each of the 5 minutes. Whereas, in the second plot, the first sliding window is considered the initial moment 0 and incremented by one for each of the sliding windows.

In the first plot, irradiation and the DC current increases proportionally with each other before the fault occurs. In the time when fault happens (moment 82 corresponding to time 02:55 PM) the current decreases immediately to 0, while irradiance decreases normally as the evening is coming.



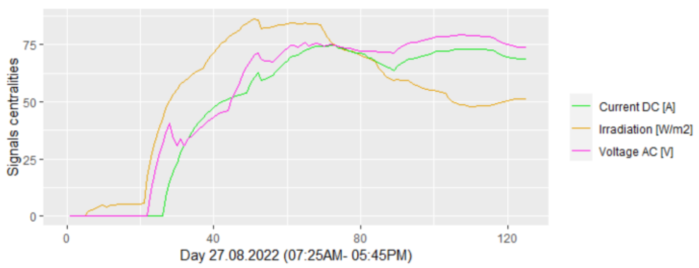


Figure 2. Comparison between signals time series data and weighted degree centralities

In the second plot it is clear that weighted node degree centralities are positively correlated to each other before the fault happens. After the fault, it is seen that the irradiation decreases while the DC current and AC voltage increases and remain positively correlated with each other.

Discussion

In this study we have considered one fault and taken in consideration only one inverter. Furthermore, we are based only on the weighted node centralities of the networks constructed. Our intention for future work is to use all the information obtained from the sensors in the PV plants and to analyze if we can extract more valuable information about the time and the sensor where a fault occurs by extending our focus from the weighted degree centrality to other centralities and to the usage of modularity to detect communities in networks, where these communities may be time intervals or sensors where a fault is detected.

Conclusion

We have shown in this study that complex network analysis can be a powerful tool in identifying faults in photovoltaic plants. We concluded that we can reveal meaningful information from the weighted degree centralities and these are important in detecting the moment when a fault occurs. One fault in PV plants implies that the weighted degree centrality of the irradiation is not positively correlated with the weighted degree centrality of the power and voltage. Table 2 shows the changes in the correlation before and after fault occurs.

Table 2. Correlations between weighted degree centralities before and after fault occurs

	Irradiance	DC Current	L1 AC Voltage
Irradiance	1	0.89062/ **-0.36066**	0.90268/ **-0.19876**
DC Current	0.89062/ **-0.36066**	1	0.97493/ 0.98425
L1 AC Voltage	0.90268/ **-0.19876**	0.97493/ 0.98425	1

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