Solar Radiation Reduction Monitoring of Macao World Heritage District Photovoltaic System Using GIS and UHF RFID Obstacle Detection Approach

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***Abstract*— In this paper, the solar radiation reduction monitoring of Macao world heritage district photovoltaic system using Geographical Information System (GIS) – Google Earth and 920-MHz Ultra-High Frequency Radio Frequency Identification (UHF RFID) obstacle detection approach is presented. When the solar panel is tagged with UHF RFID tag, its tag antenna effective area can be significantly affected if there is obstacle placed between tag and reader. An experimental trial of tag's Received Signal Strength Index (RSSI) reports more than 6 dB difference with and without obstacle. This property is a simple and economic solution for photovoltaic system to detect obstacle shadowing or covering the solar panel and; efficient solar radiation reduction monitoring can be easily integrated with existing photovoltaic GIS platform demonstrated.**

Keywords*— *Solar radiation, BIPV, GIS, RFID, RSSI.

I. INTRODUCTION

In the past decades, the global warming and the severe depletion of fossil fuels resulted in the urgent need of the use and development of renewable energy sources for the sake of environmental responsibility like CO_2 emission reduction. Amongst many renewable energies, the power from sun intercepted by the earth is as high as 1.8 x 108 GW that is in fact the largest renewable energy source. Solar energy is the more acceptable and promising renewable energy source due to its inexhaustible and pollution-free characteristics. By the end of 2019 and; along the development of photovoltaic elements, the world's installed solar energy capacity has reached 586 GW and there are still rooms of solar energy for massive deployment in next decades [1][2].

From the building and electrical engineering aspects, Building Integrated Photovoltaic Systems (BIPV) as in Fig. 1 is one of the major approaches. The photovoltaic modules of the above systems are integrated with the building roof or façade and the commonly used photovoltaic modules are solar panels. These panels double the function of architectural appearance with energy generation. The system can be in grid or off grid operation and evaluation of BIPV includes solar cell efficiency relevant to projected lighting surface area; open circuit voltage and; short circuit current and so forth. Therefore, the integration of solar cell area and design into buildings remains the challenge and; historic buildings are no exception.

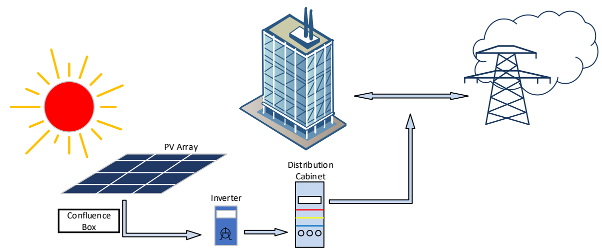

Fig. 1. Traditional BIPV.

Fig. 2. Macao World Heritage district centered around Ruins of St. Paul's by Google Earth (old and; historical buildings as well as; tree centered around Ruins with radius of ~100m)

For example, World Heritage historic buildings and districts are collective evidence of civilization, unique and irreproducible memories for some cities and countries. The protection and conservation of appearance and physical structure with innovative technologies are fundamental but the innovation energy sources are always lacking in these old buildings and districts. The use of solar energy becomes crucial approach to the above World Heritage protection and conservation in general. Some studies report the use of solar energy onto the historical districts. In [3], the possibility of powering the historical Venetian Villas with submerged photovoltaic plant integrated with existing water basin was discussed. In [4], few renewable solar energy solutions for heritage historic buildings are presented together with some examples of solar panels in windows; balcony; terrace and; tilted roofs. A much complete review of energy retrofits in historic and traditional buildings is given in [5].

One of challenges of BIPV in historic and traditional buildings is about the surrounding obstacles shadowing or covering the solar panels. Such shadow and cover impacts can significantly reduce the solar exposure of BIPV like obstructing incoming solar radiation by tree and; leaves as reported in [6]. An example heritage district with some trees around is shown in Fig. 2. It is Ruins of St. Paul's of World Heritage and the ruins of a 17th century catholic religious complex in Macao, China and; it was the old Portuguese church and now restored by government into a museum, and the façade is now buttressed with concrete and steel in a way conserving aesthetic integrity. Around this ruins, there are now old, historic buildings together with some trees in the small mountain nearby. The use of BIPV for these buildings is fundamental to the energy source of innovation conservation in future as the energy capacity is limited due to the physical protection of districts of World Heritage. It is thus necessary to provide some innovative solution of such obstacle shadowing and covering detection to existing BIPV with compact size, reduced weight, economic and seamless integration. To this end, this paper proposes an economic UHF RFID approach to detect obstacle for solar panel over the GIS based solar radiation estimation platform. UHF RFID tags are attached to the solar panels due to their compactness and ease of integration. Using tag signal change due to obstacle between tags and reader, simple detection function could be introduced to existing BIPV.

Besides this introductory section, section II briefly describes the basics of obstacle detection by UHF RFID. Its experimental setup and the measurement results of RSSI due to obstacle placed between tags and reader are given in section III. In section IV, energy estimation of photovoltaic system based on GIS is presented in consideration of solar radiation variation. Finally, the conclusion is drawn in section V.

II. UHF RFID Obstacle Detection

RFID system operated in UHF is based on the half duplex mode of backscattering communication as shown in Fig. 3. The forward link is sending waves with energy to UHF tags. The return link is receiving the signal from UHF tag to reader.

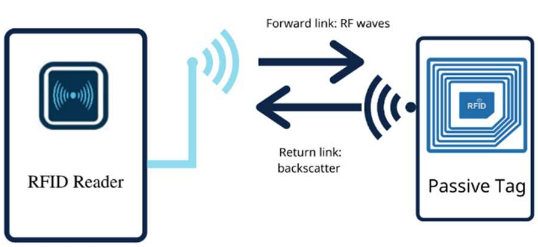

Fig. 3. Principle of backscattering.

The reader receives the response and then calculates and analyzes the signal's Received signal strength indication (RSSI) in dBm. RSSI is used to measure the strength of the power received from the returned signal by RFID tag. The typical range of RSSI is from -30 dBm to -85 dBm. It means how well each tag will respond to the reader. Applying backscattering mode in UHF passive tags; the reader broadcasts larger RF wave energy with higher RSSI if the tags are without any obstructions. When some material separation or obstacles are placed between tag and reader, the RSSI will be lower because the transmitted signal becomes weaker. This simple mechanism allows some economic solution of such obstacle shadowing and covering detection to existing BIPV. In fact, the power collected by tag is proportional to the receiving area of tag antenna and; obstacle can significantly affect the receiving tag power. In fact, the effective receiving area of tag's antenna Ae is given by

$$A_e = \frac{\lambda^2}{4\pi} G_{Tag} \tag{1}$$

where λ is the electric length of frequency of operation and; GTag is antenna gain. In next section, some experimental trials of RSSI variation of obstacle effect placed between tags and reader.

III. RSSI of UHF RFID Passive Tag Influenced by Obstacles

The experiment performs the testing of the tag's antenna influenced by obstacle denoted by hand in proximity shown in Fig. 4. The UHF RFID passive tag fixed on the board and 1.5 m away from the reader. The passive tag changes four directions shown in Fig. 5 and performs testing. The obstacle is placed between the tag and the reader, ranging from the 50 cm away from the reader. The reader scans the tag 500 times. And then the obstacle moves to 70 cm and 100 cm in the direction of the reader.

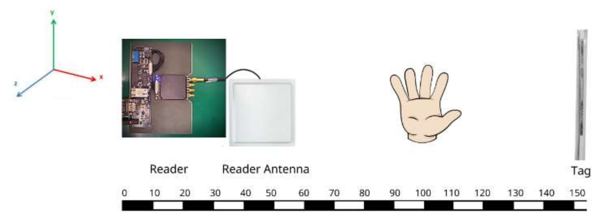

Fig. 4. Obstacle detection experiment.

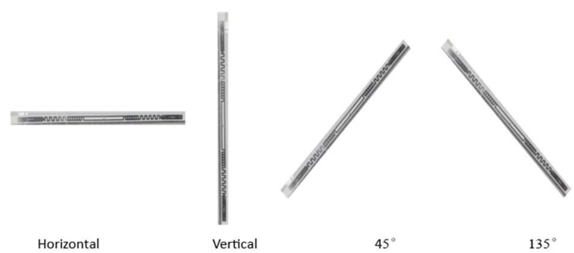

Fig. 5. The tag orientation.

This experiment studies the signal strength relationship between tag orientation and hand. We use a single tag to measure a reference value of RSSI. The first scenario is about the passive tag fixed in horizontal position reference of the ground. The obstacle movement starts from 50 cm to 150 cm.

The result is recorded in Fig. 6, obstacle moves from 50 cm, 70 cm and 100 cm from the reader, the RSSI is bounded from -64 dBm to -50 dBm window as observed. Before performing the testing of contactless by obstacle movement, we scan the tag 500 times as the reference value. In Fig. 6, the reference RSSI is ranged from -56 dBm to -52 dBm. When the obstacle distance to the reader is 50 cm, the RSSI range is -63 dBm to -57 dBm. The obstacle distance to the reader is 70 cm, and the RSSI range is changed to -50 dBm neighborhood with 6dB margin. In comparison, it is obvious that the RSSI change is much differentiable at 50 cm and it is good enough as the obstacle proximity detection neighborhood. When the tag is in some other directions like the vertical direction. Similar RSSI variation is observed and normal horizontal orientation is used to ease the standard engineering work.

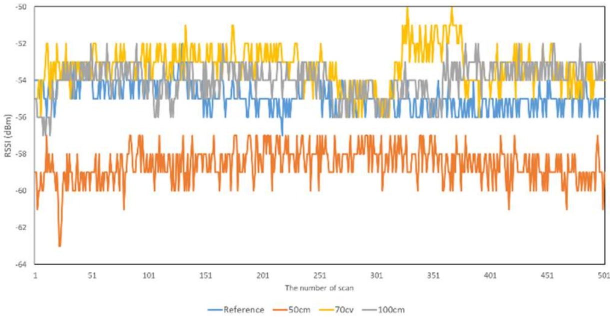

Fig. 6. RSSI measurement for horizontal tag against obstacle in different distance.

IV. Solar Radiation Reduction Estimation in GIS Platform

A. Macao World Heritage District

Like section I, an example heritage district in Macao - Ruins of St. Paul's is discussed as shown in Fig. 7 and there are 5 possible BIPV sites identified as Building#1 to #5. The Ruins of St. Paul's is World Heritage that is about 17th century catholic religious complex in Macao, China and; it is the mixture of old, historical; mountain and tree around this Ruins. In addition, the regions bounded by red line are the transitional districts for protection. These 5 rooftop areas are estimated as 940 m^2; 150 m^2; 250 m^2; 370 m^2 and; 750 m^2 by Google Earth.

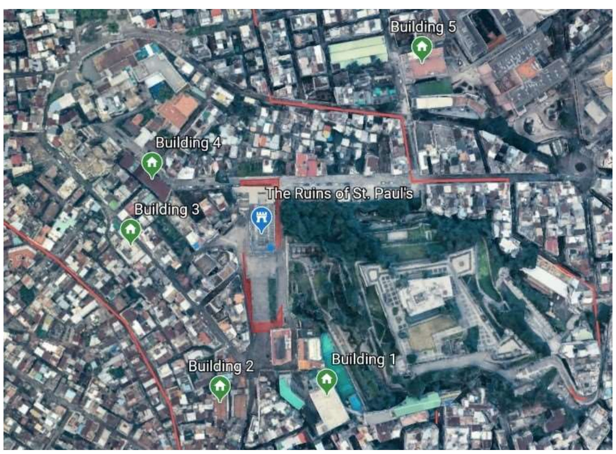

Fig. 7. 5 BIPV sites near World Heritage District of Ruins of St. Paul's.

B. Solar Radiation Reduction Estimation

According to section III, solar radiation variation influenced by obstacle is found around 6 dB (~50%) if the RFID tags are attached to the panel and used as the detection tool. To this end, relevant variation is input into an open GIS platform - photovoltaic energy estimation platform of PVWatts [7]. For Building#1 with average solar radiation of 4.1 kWh/m2/day, using PVWatts in reference to normal solar radiation without obstacle, the momentary value generated is listed in Table I below. The maximum monthly value reaches 4,700 USD in summer and annual economical gain of 45,000 USD is estimated. Similar estimation is given for other four buildings and they are compared in Table II.

TABLE I. Solar energy economic gain of Building#1 without obstacle.

Month	Solar Radiation (kWh/m²/day)	AC Energy (kWh)	Value (USD)
January	3.4	7,504	3226.72
February	2.69	5,404	2323.72
March	2.73	5,967	2565.81
April	2.63	5,541	2382.63
May	4.54	9,789	4209.27
June	4.5	9,232	3969.76
July	5.34	11,325	4869.75
August	4.86	10,277	4419.11
September	5.3	10,958	4711.94
October	5.11	10,957	4711.51
November	4.27	9,022	3879.46
December	3.85	8,510	3659.3
Annual	4.1	104,486	44,929

TABLE II. Comparison of solar energy gain of five buildings without obstacles.

	Total area available （m²）	Installation area （m²）	Installation capacity （kW）	Estimated annual production （kWh）
Building 1	940	560	90	104486
Building 2	150	90	14.4	16719
Building 3	250	75	12	13933
Building 4	370	222	35.5	41216
Building 5	750	225	36	41796

In real case, the occlusion of obstacles such as dust and trees will greatly affect the power output of PV. In [8-10], the impact of dust deposition on PV panels were verified by experiments. In [11], the average power attenuation was compared under 4 scenarios as listed in Fig. 8.

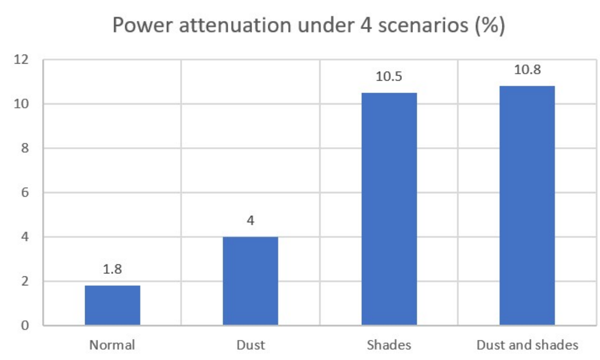

Fig. 8. Power attenuation of PV under different scenario.

The shadow in this study only occurred before 9:30 and after 15:30. If it was between 11:00-14:00, the impact would be more significant. This will also directly affect the economic benefits of the project.

V. Conclusion

This paper presents the novel RSSI based approach of obstacle detection of PV panel and; the experimental correlation of effective antenna area of tag with different obstacle placed in between UHF RFID reader was discussed and analyzed. It is found that there is 6 dB RSSI difference with and without the obstacle. This UHF RFID approach can be easily integrated with existing photovoltaic GIS platform for solar energy economic gain monitoring.

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