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978-1-7281-4160-2/19/$31.00 ©2019 IEEE Modelling of Monthly Clear Sky Solar Irradiation on Horizontal Surface in Denpasar City Anak Agung Ngurah Gde Sapteka Electrical Department Politeknik Negeri Bali Denpasar, Indonesia sapteka@pnb.ac.id Ponlakit Jariyatantiwait Electronics and Telecommunication Department Rajmangala 12 University of Technology Phra Nakhon Bangkok, Thailand ponlakit.j@rmutp.ac.th Anak Agung Ngurah Made Narottama Electrical Department Politeknik Negeri Bali Denpasar, Indonesia narottama@pnb.ac.id I Made Sajayasa Electrical 10 Department Politeknik Negeri Bali Denpasar, Bali madesajayasa@pnb.ac.id Kadek Amerta Yasa Electrical Department Politeknik Negeri Bali Denpasar, Indonesia amerta.yasa@pnb.ac.id

Abstract—This article discusses the monthly clear sky solar irradiation in Denpasar City from April to October, focusing on the effect of June Solstice. The primary data of daily solar irradiation on horizontal surface is taken using Lutron SPM1116SDfrom 8 o'clock to 16 o'clock in minute basis. The data is filtered using second order polynomial fitting. Only data with adjusted R-square more than 0.9 is included. If it is needed, the upper envelope signal processing is taken before second order polynomial fitting.By integrating this data, we have daily solar irradiation data on horizontal surface in Watt hour per square meter and a precise model of monthly clear sky solar irradiation using third order polynomial.

Keywords—modelling,solar irradiation,irradiance, horizontal surface,denpasar, bali

I. INTRODUCTION

The sun moves from position above the equator on March 21 towards the June Solstice(230 26' 12.3" north of equator) on June 21. Furthermore, the movement of the earth's axis causes the movement of the sun to return to the equator on September 23 and is continued to reach the DecemberSolstice (230 26' 12.3" south of equator) on December 22. The 7 position of the sun then returns to the equator on March 21. This regular movement causes repeated solar irradiation every year at certain locations on the surface of the earth.In Surabaya, Indonesia, the monthly solar irradiation averageis 4.92 kWh/m 2 in 2008 [1]. In Medan, Indonesia, 2 the minimum and maximum estimations of irradiance are 522.19 W/m2 in December and671.69 W/m2 in August [2]. In Pontianak, Indonesia, solar

irradiation reaches 7.71kWh/m2 on March 10, reaching a minimum value of6.78 kWh/m2, with possible local maximum of 7.62 kWh/m2 on June 22 and reaching a maximum value of 671.69 W/m2 in August [3]. Due to the variety in solar irradiation, there are several modelshave been studied about this subject such as: Genetic algorithms to optimize the direction and angle of installation of solar panels in Sabang, Indonesia [4];Solar energy potential 8 in Indonesia using artificial neural networks (ANNs) method in Makassar[5]. The ANNs method is also used in the cities of Pekanbaru, Bandung, Banjarmasin and Gorontalo [6].Meanwhile in Jakarta, solar radiation modelling is based on the calculation of mean bias error and root mean square error [7]. In this research we report about modelling of monthly clear sky solar radiation on horizontal surface in Denpasar City, Bali. II. METHODOLOGY We collect the data of solar irradiation at Denpasar City, Bali, Indonesia. It is located at 8039' S, 115013' E. We use Lutron Solar Power Meter (SPM-1116SD) to collect the daily data in Watt/m 2on minute basis from April to October in 2018 and 2019. The irradiation sensor of LutronSolar Power Meter SPM-1116SD is placed in a horizontal position as shown in Fig 1. Fig. 1. Lutron SPM-1116SD. The daily data is collected every minute from 08.00 to 16.00 local time. By integrating this data, we have solar irradiation data in Wh/m 2. Then the data is fitted using second order polynomial fit. Only data with adjusted Rsquare more than 0.9 is included. If it is needed, the upper envelope signal processing is taken before second order polynomial fitting. So that only the data on sunny days will be processed further to be monthly data. Furthermore, the monthly data is fitted to obtain the appropriate mathematical model. III. RESULT AND DISCUSSION A. Solar Irradiation Data Data collection begins on April 2018 in Denpasar City. On that month, the average sun declination at 4.510 and the average sun elevation at 71.700.On April 18, 2018, it has maximum irradiance value of 1036 W/m2, as shown in Fig.2. On May 2018, the average sun declination at 18.860 and the average sun elevation at 62.490. The maximum irradiance level onMay 6, 2018 is870 W/m 2, lower than April as shown inFig. 3. On June 2018, the sun is approaching June Solstice, so the maximum irradiance level has value of 867 W/m 2on June 6, 2018, which is lower than May as shown in Fig. 4.On

 sun elevation at 58.290. The irradiance level still decreases on July although the sun has already moved to the equator. As shown in Fig. 5, the maximum irradiance on July 20, 2018 is 830 W/m2. The increase of irradiance level begins on August. On August 15, 2018, the maximum irradiance level is 959 W/m 2, as shown in Fig. 6.The average sun declination at 13.610 and the average sun elevation at 67.740. On September, the sun is approaching equator. The average sun declination at 2.830 and the average sun elevation at 78.520. On September 30, 2018, the maximum irradiance level is 976 W/m 2, as shown in Fig. 7. On October, the average sun declination at -8.760 and the average sun elevation at 87.160. The sun is right above Denpasar at noon on October 15, 2018. As shown in Fig. 8, the maximum irradiance level is 1001 W/m 2 on October 3, 2018. Fig. 2. Irradiance on April 18, 2018. Fig. 3. Irradiance on May 6, 2018. Fig. 4. Irradiance on June 6, 2019. Fig. 5. Irradiance on July 20, 2018. Fig 6. Irradiance on August 15, 2018. Fig. 7. Irradiance on September 30, 2018.

 Fig. 8. Irradiance onOctober 3,2018. TABLE I. SOLAR I RRADIATION STATISTIC Month No. of Days Mean (Wh/m 2) Min (Wh/m 2) Max (Wh/m 2) April 12 6179.64 5618.78 6747.23 May 16 5200.46 4645.23 5762.80 June 4 5112.32 4636.14 5289.44 July 8 4992.19 4306.95 5316.54 August 6 5391.75 5066.41 5717.09 September 4 6009.49 5919.93 6071.98 October 7 6066.65 5810.86 6334.49 By integrating the daily irradiance data, the mean, minimum, median and

maximum values of daily solar irradiation can be determined as shown in Table I. Number of days in Table I shows the amount of sunny days in a certain month which is calculated statistically in Denpasar City, Bali. B. Modelling The movement of the sun towards JuneSolstice fromMarch 21 to June 21 causes reduction of solar irradiation on horizontal surface in Denpasar. Mean, minimum and maximum values of solar irradiation are still decreasing until July even though the sun has moved towards the equator. This phenomenon is consistent with the results obtained in other locations as stated in [6]. Mean, minimum and maximum values of solar irradiation are increasing from August to October. According to the data in Table I, we propose a 3rd order polynomial equation to determine daily solar irradiation on horizontal surface in Denpasar City from April to October as stated in Eq. 1. In this equation, the value of y represents daily solar irradiation in Watt hour per square meter (Wh/m 2), meanwhile x represents the month number. The values of intercept, B1, B2 and B3 are written in Table II. The fitness level of this equation is shown Adjusted RSquare value of 0.91 as shown in Fig. 9. = Intercept + B1 × + B2 × + B3 × (1) TABLE II. FITNESS OF THIRD ORDER POLYNOMIALEQUATION Statistic Value Number of Points 7 Degrees of Freedom 3 Residual Sum of Squares 63805.11 R-Square(COD) 0.95 Adj. R-Square 0.91 Intercept 20210.28 B1 -6241.70 B2 816.92 B3 -33.37 Fig. 9. 3rd order polynomial fit of solar irradiation. Compared to other models [4-7], this equation does not require other parameters such as temperature, humidity and so forth. As shownin Fig.9,the Equation (1) can predictmonthly clear sky solar irradiation on horizontal surface in Denpasar City from April to September. IV. CONCLUSION In this research, we recommend a mathematical model using 3rd order polynomial to calculate monthly clear sky solar irradiation on horizontal surface in Denpasar City from April to October as stated in Eq. 1. This equation is statistically fit with adjusted R-square value 0.91. ACKNOWLEDGMENT We would like to thank to the Center of Research and Community Service (P3M) Politeknik Negeri Bali for funding this research. REFERENCES [1] E. Tarigan, ”Evaluation of the solar energy potential for photovoltaic system in Surabaya,” Proceeding of the 2015 International Conference on

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