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Optimization model and development of power estimation in photovoltaics for self-load consumption

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Article Info

ABSTRACT

The Indonesian government's initiative to meet a renewable electricity supply 2050 of around 100% and its ecological benefits, has an impact on the big challenge where the increasing number of photovoltaic (PV) systems due to high power input and risks to electricity network security conditioned sunny weather for a long time. This research aims to provide predictable power output for network operators, thereby enabling longer planning periods and increasing the protection of the national operational network. Independent consumption by household consumers will impact household energy behavior and affect the security of the electricity network. Consumption itself provides an incentive to increase the cost of energy use which will be much higher than the compensation received, so software is needed which can support PV system prediction patterns. This pattern will close the gap in software development in the process of implementing optimization and configuration based on PV estimates. The consumption planning optimization algorithm itself validates the predetermined scenario optimization process. This research contributes to the efficiency and stability of energy use in households.

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1. INTRODUCTION

In 2050, the use of new and renewable energy is increasing by around 80% and investment and planning are needed for photovoltaic (PV) systems. However, the government has taken the initiative to provide up to 100% renewable energy in the same year [1]. However, this expansion will bring challenges to lots of energy generated and required in favorable weather conditions, and an increase in electrical power can disrupt the distribution network. An important event illustrating this problem occurred on September 13, 2023, when there was a disturbance in the electricity network, and the PV system had to be turned off [2]. The PV prediction method is a solution for developing energy storage models and flexible energy use patterns in improving PV systems [3]. The preventive model is one solution to overcome the network security crisis and improve operator skills to overcome conditions like this [4], [5].

Besides that, Indonesia still plays an important role in network security for independent energy use [6]. Indonesia has recorded 1,172 kWh/capita, based on the Director General of New and Renewable Energy in 2022 according to the target of 5.3% in 2023. Indonesia with independent energy use will have an impact on adding 25% of total annual energy in 2020 [7], [8]. However, it impacts the operation of the PV system

for 2.6 million people on the electricity network served by the new renewable energy system. This impact is felt directly by electricity network users and results in a reduction in national energy consumption. This research was supported by [6], as private households only pay around IDR 1,467.28 (0.093USD) for each kWh supplied to the grid [9], while each kWh purchased by electricity producers is worth around IDR 2,253 (0.14 USD) [10], then the economic aspect also motivates households to increase energy consumption.

The development of program models for forecasting and algorithms on new and renewable energy for electricity grid operators has limited opportunities for increasing residential energy consumption. The development of smart home technology continues to increase along with improvements in technology used for scheduling, scenarios, and management of independent energy use, including regulating the use of equipment in residential homes [11]. The contribution of this research is to develop software used by customers and plan household equipment to optimize energy consumption.

The PV forecasting system is subjected to quality testing and the results are compared to the software created. Data collection is obtained from prediction results, analysis of the loads used in the household, and using a numerical optimization algorithm to make recommendations for taking action. Implementation and optimization of software for consumer constellations on time-controlled or manual smart homes and analyze the impact of using this software on electricity consumption, electricity supply, power grids, and economic efficiency.

2. METHOD

The research method is explained in subsection 2.1 regarding PV system forecasting models, subsection 2.2 explains the accuracy of the PV system approach model and subsection 2.3 explains the comparison of PV system approach models.

2.1. Photovoltaic prediction model

The PV prediction model uses mathematical and physical models and parameters obtained from meteorological data are used to calculate PV output power. This modeling is sensitive to changing weather behavior with the advantage of being without historical data sets [12]. Probability modeling and matching for the PV system approach are obtained from the parameters and history. The model proposed by [13], [14], using a physical model is more acceptable because it ignores errors in measurements to determine certain input parameters, but mathematical models require a database and high accuracy. To solve this problem, a hybrid system between statistical and physical models is needed, where the values from the modeling are used as parameters for further modeling. Determining PV prediction modeling requires forecast data for different times.

Forecasting will be accurate if the support of the weather horizon and references are good and reliable [15], [16] where, the forecast error is positively correlated with the period. The accuracy of planning and execution time will depend on the 24-hour prediction horizon. Horizontal predictions and resolution of the forecast profile will influence the results of the forecast model [17]. Power fluctuations can occur every second, but resolution is impossible for PV predictions, therefore a resolution option every 30 minutes is needed as an acceptable compromise model for errors caused by changes in power to the consumers served.

2.2. Photovoltaic approach model

The PV approach model is obtained from the deviation of predicted and actual data. For accuracy against errors, use the root of mean square error (RMSE), mean average error (MAE), and mean absolute percentage error (MAPE) models, but the best RMSE model for evaluating predictions is the PV approach [18], [19]. The PV approach model using a horizontal approach is the best choice due to the sensitivity of its extreme values. Comparison in the implementation of the error metric as a system output model, so that differences in power output are made based on the normal value and the average production is implemented in the PV system [20], [21].

The right approach is to use the power of prediction P_T, real power P_t, the number of measured values M, and installed power $P_{install}$, as explained in (1):

$$RMSE_{normalized} = \frac{\sqrt{\frac{1}{M}\sum_{t=1}(P_t - P_{install})^2}}{P_{install}} \qquad (1)$$

The metric error value becomes a model that shows the accuracy of the forecasting model for a PV plant. The use of different modeling results in the results obtained will also be different [22]. The modeling used illustrates that metric error values with different actions will give different values [23]. Power estimates of economic behavior and control at large power will provide an insignificant assessment. The causes of insignificance will depend on the changing quality of the modeling and the method chosen for consideration in decision-making. The forecasting process for PV system modeling uses an approach as in Figure 1.
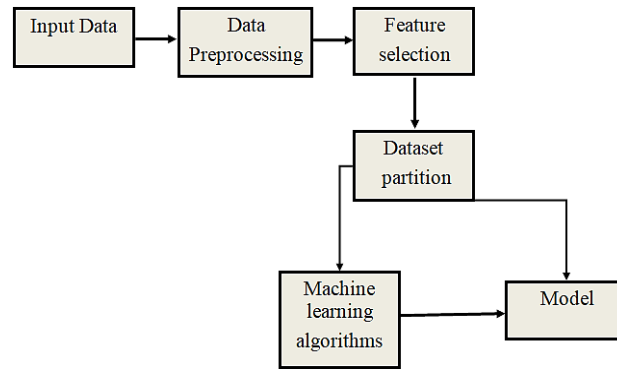
Figure 1. Observed PV system forecasting process model

Figure 1 explains several provisions as follows:
- Input data: input data from physical and mathematical models to provide appropriate forecasting values to be simulated for the observed PV system.
- Preprocessing data: this data is very important because the data obtained is often random and not yet standard for further processing.
- Feature selection: data that is not yet standard needs to be increased in accuracy in machine modeling, so that it will affect the results obtained.
- Dataset partition: this data is for identification in determining the size of the data that will be used in research and the accuracy of forecasting.
- Machine learning algorithm: data used as training in algorithms and learning in PV systems.
- Model: the data obtained is modeled to forecast the PV system to produce the best value.

2.3. Photovoltaic prediction modeling

PV prediction modeling is the choice used and checking the alignment of the software used for quality and accuracy. Table 1 provides very important prediction results in PV power predictions for 60 days which are adjusted to the PV system used. The modeling of two systems, namely the actual system and the prediction, is given in Table 2. Comparison between the two systems for the RMSE model and the results are shown in Table 3, where the statistical values, accuracy, and quality of the modeling for PV 800 W are 13.18%, 11.63%, and 13.48% respectively, which are used as corrections for the software.

Table 1. Models and PV forecasting are used

No.	Model type	Solar radiation	Forecast weather	Consider cloud cover	Determination PV power
1	Statistics	PV data	Various forecasting tools	Unclear	Unclear
2	Accuracy	Simulation	Simulation	Unclear	Simulation
3	Quality	Simulation	Simulation	Unclear	Simulation

Table 2. PV system conditions at different slopes

No.	Longitude (°)	Latitude (°)	Slope (°)	Azimuth (°)	Installed power (W)
1	52.9	11.7	30	180	800
			5	90	426
2	53.5	12.8	5	270	426

Table 3. Accuracy results of RMSE prediction modeling for PV systems

	RMSE forecast PV system (%)	RMSE accuracy (%)	RMSE quality (%)
System, 850 W	13.18	11.63	13.48
System, 850 W	11.98	16.12	13.55
Total	12.59	14.09	13.51

The results shown in Table 3 show that the RMSE model error is quite low and the proposed modeling is acceptable. This PV forecast modeling has high accuracy, but does not have significant

specificity and has average and strong categories. There are still errors in forecasting, but they do not interfere with the expected results, because the graphical representation has actual values. Optimization of PV forecasting modeling can provide improvements to independent energy consumption and produce energy needed by consumers when PV power is not available. Physical forecasting modeling provides medium accuracy and errors occur due to high power.

3.   RESULTS AND DISCUSSION
3.1. Energy consumers
        Energy consumer profiles are needed as consideration for optimizing independent consumption of PV output. Effects on data sources, load conditions, and household equipment were independently recorded. However, load conditions are not used directly as a data source in this program optimization. The data recorded is based on standards that are valid for one minute, so changes in load affect the recorded data.
        The use of energy consumption data is decomposed into a temporal distribution adjusted to the PV forecasting conditions. The peak load condition for a short duration is the amount of residential equipment used by selecting an accuracy model for time and energy in the load profile [24]. In this method, the total energy requirement is taken into consideration at peak load for 30 minutes. This model is considered to represent part of the energy requirements used for holistic optimization [25]. The basic program is used for user and load profiles stored in the software. The available load conditions can represent all load profiles used in housing and simple imports so that the optimal consumer constellation is a digital model in the software.

3.2. Optimization algorithm
        The consumer constellation program uses an optimization algorithm for maximum self-load. However, minimizing the external energy required is adjusting the PV power to the predicted needs [26]. Additional real expenses can affect the economic efficiency of the optimization process, with the aim of numeracy optimization being used as a consideration. Algorithmic numeracy model to examine the temporal constellation of consumers to identify their lowest energy users. The total number of consumers will not affect computing efficiency, but this effort is still within the allowable tolerance. The enumeration method for overall optimization will provide 100% profit without any stopping criteria.

3.3. Software development
        PV prediction modeling with load profiles and optimization of software developments will meet the specified requirements. The development concept for implementing this program is through existing cross-platforms such as the *Python* language, while code execution is used from programs that have been created without using other platforms such as *Windows* and *Linuxabove*. The use of this software aims to increase energy consumption for independent use in housing.

3.4. Software
        A representative scenario for energy determination is an investigation of the power grid using consumer-intuitive software. This model was created to determine its effect on the economic efficiency of energy use and network security in housing. In addition, this scenario is based on an imaginary housing model consisting of three members in one family, including the use of a pool which is only used in summer conditions.
        The simulation of this pattern with the loads and equipment used is recorded and analyzed for implementation of the program created for the PV system. A consumer constellation is an optimization program for independent energy use for a certain period. Comparison of simulations without a program results in intuitive energy consumption that cannot be controlled properly when the sun is at its highest point.
        The use of programs for analysis can provide a solution for independent energy use for 60 days and will reduce energy use from the electricity network and distribution network. However, the differences between scenarios are smaller than expected. The dominance of customers with relatively low per capita energy consumption (972 kWh/capita per year), so that the loss achieved is higher compared to developed countries with greater per capita electricity consumption, where energy distribution to the electricity grid is around 25 kWh lower.
        Optimization of the equipment constellation will have an impact on its limiting effects so that a PV system oriented towards the sun's movement is considered to be the right choice to obtain peak power values in the middle of the day. This model is an intuitive operating model to avoid differences with the models studied. The forecast for quality will influence the potential of PV power testing and deviations from intuitive models of self-contained energy consumption. To improve forecasting with potential improvements in PV systems and their energy use and software development.

4.   CONCLUSION

Software development has the potential for forecasting PV systems in the future but with consideration of the availability of energy and equipment used. Software planning and development are recommended regarding changes in maximum load times. Apart from that, it is also recommended for consumer constellations whose energy consumption can be controlled and evaluated. Software is used to model operational systems in general and can be applied and easy to use by energy consumers.

The scenario for the potential use of independent energy is the best option for saving energy in housing and although it has an impact on economic efficiency and network security in certain conditions, in general, it provides positive network stability for consumers. The PV system company recommends this program for residential energy services. Progress in perspective and technical energy forecasting modeling has provided a PV system forecasting model for the general interest and the development of this program can be used in large companies because it can be analyzed and researched further.

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