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HOMER AND VIPOR SOFTWARE SIMULATION RESULTS OF A HYBRID POWER PLANT CASE STUDY AT BENGKUNAT, WEST LAMPUNG

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ABSTRACT

From the ViPOR software simulation results, it has been found that the length of the distribution network of a hybrid power plant at Bengkunat is 32.055 m, it requires eight transformers each with an maximum energy requirement of 45.1 kWh per day. Compared to a 2 x 100 kW diesel power plant (NPC = $ 505.493), the NPC value of the hybrid power plant is higher ($ 555.956), also its COE ($ 0.770 per kWh) is higher than the diesel power plant ($ 0,739 per kWh). The hybrid power plant will save 128,061 liters of fuel per year. The hybrid power plant is feasible to be applied in areas with enough wind and sun radiation resources such as at Bengkunat West Lampung.

The ViPOR software has several shortcomings such as : only step down transformers can be used for simulation, and only with one capacity. For a load configuration that requires a different transformer capacity, the simulation can not be done. The optimization based on the NPC value, not based on the voltage drop at the network, because this software doesn't have outputs of the voltage drop, power losses and power flow.

Keywords :
Hybrid power plant, simulation, optimization, distribution network, ViPOR, HOMER

1. INTRODUCTION

Bengkunat located on the west coast of Sumatra Island with geographical position 5°20'02,05" S - 5°56'40,83" S and 104°03'41,06" E - 104°39'12,41" E. Economic activity of society rests on the plantations, forest products (particularly resin), agriculture, fisheries and tourism (beaches, surfing and fishing blue marlin). West Lampung is a producer of export quality fish like Blue Marlin, Tuna, Lobster and others [1].

The output of this study is to analyze the optimal configuration of distribution network of the hybrid power plant model, which is the integration between the diesel power plant based on fuel, with PV modules and wind turbine based on renewable energy. The result is the total load to be supplied per day, the cost of electricity (COE), distribution network and the number of transformers. Data processing using HOMER software for the simulation of power generation, where the simulation results are input to ViPOR software, which is used to simulate the distribution network model.

2. THE HYBRID POWER PLANT

The hybrid power plant [2] is a combination of power plant based on non-renewable energy with power plant based on renewable energy. The hybrid power plant is a solution to overcome the fuel crisis and the lack of electricity in remote areas, small islands and urban areas. An example of a hybrid power plant consisting of PV modules, wind turbines, diesel generators, batteries, and an integrated control equipment. The purpose of the hybrid power plant is to combine the advantages of each plant as well as cover the weaknesses of each power plant to certain conditions, so that the whole system can operate more economically and efficiently.

To determine the performance of the hybrid power plant, several things to consider is the load characteristics and the characteristics of power generation, particularly renewable energy potential that want to develop, and the characteristics of the region it self, such as change of day and night, seasons etc.

3. SIMULATED ANNEALING ALGORITHM

The optimization algorithm used in ViPOR is known as simulated annealing [3,4]. The purpose of this step is to assign the demand points to the supply points in an optimal way. Simulated annealing is based on neural network, feedback networks type. Feedback networks allow for signals to transfer from the output of neuron to the input of any neuron. The neurons are the nodes in the network and the signal are the connections between the nodes. Figure 1 shows the simulation protocol of the simulated annealing process [3].

ViPOR represents the village as a set of demand point s, each of which consists of x and y coordinates [4]. The distribution grid consists of a number of transformers connected to each other by medium voltage wire and to demand points by low voltage wire. The distribution network designed by the optimization procedure is radial, which means that each demand node is supplied by a single source node. The lengths of the low voltage wire runs must be constrained in order to limit resistive losses and source-to-load voltage drops. The goal of the optimization procedure is to design the lowest cost electrification system [4].

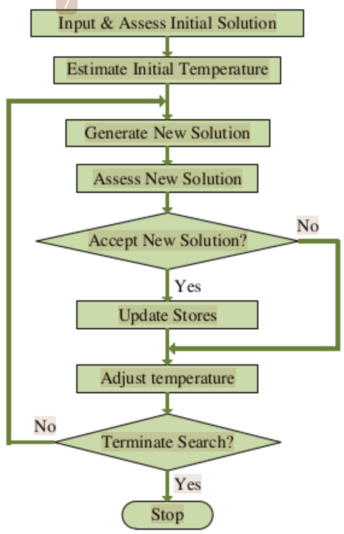


Figure 1: Simulated annealing protocol [3]

3.1 Lower Level Optimization

The lower level optimization procedure [4] consists of designing the optimum low voltage distribution system to service the set of demand nodes from a specified set of transformers. The objective of this procedure is twofold: the first objective is to decide which of the demand nodes should be included in a low voltage distribution network, and the second is to design the lowest cost distribution grid to service those nodes. The lower level simulated annealing allows three types of changes: an unconnected node can be connected to the grid, a connected node can be removed from the grid, or a connected node can be reconnected so that it receives power from a different node. The algorithm starts with the current low voltage configuration and makes modifications to that configuration.

At each step of the annealing algorithm, one of the demand nodes that does not coincide with a transformer location is chosen at random (referred to in the following discussion as node *i*). If node *i* is currently unconnected (not included in the distribution grid), a search is performed on the other nodes starting from the node nearest to node *i* and proceeding in the order of increasing distance from node *i*. Node *i* is attached to the first node found that is currently connected to the grid and whose connection to node *i* would not violate the maximum low voltage line length constraint.

If a valid modification can be made to the low voltage distribution grid, the simulated annealing routine will make the modification and evaluate the resulting change in total life cycle cost. If the change results in a eduction in total cost, it is node accepted unconditionally. If the change results in an increase in total cost, the value of P(ΔE) is calculated [4] based on Equation (3.1):

$$P(\Delta E) = \exp\left(\frac{-\Delta E}{T}\right) \qquad (3.1)$$

where ΔE is the change in total cost and T is the current temperature (not a physical temperature, but rather a control parameter which can be changed as the algorithm proceeds). A random number between 0 and 1 is then generated and compared with $P(\Delta E)$. The change is accepted if the random number is less than $P(\Delta E)$. The temperature is initially set to a relatively high value ($T_{i,l}$), and is then multiplied by an *annealing factor* (α_l , a number between 0 and 1) after every *accepted* modification to the system. The temperature is not changed after rejected modifications. The algorithm stops when the temperature reaches a freezing point ($T_{i,l}$) or after a certain number of consecutive rejected modifications ($R_{max,l}$). The lowest cost configuration found during the course of the algorithm is chosen as the optimum [4].

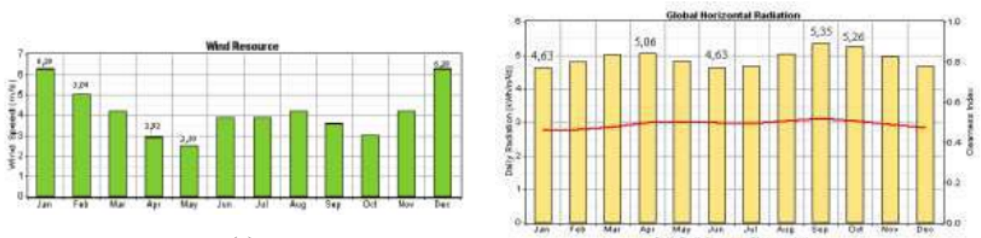
3.2 Upper Level Optimization

The upper level [4] routine must therefore do three things: it must optimize the number and location of transformers, select the optimum source location, and design the optimum medium voltage distribution grid to connect the source location and the transformers. The upper level annealing algorithm is permitted to make four types of changes to the system: the addition of a transformer, the removal of a transformer, the movement of a transformer, and a change of source location.

The upper level simulated annealing algorithm starts with the current medium voltage configuration, which can be specified by the user, and makes modifications to that configuration. After each modification is made to the medium voltage configuration, one of the three lower level optimization routines is called to design the low voltage configuration and calculate the objective function. The modification is then accepted or rejected based on equation (3.1). The temperature of the upper level annealing algorithm is independent of the temperature of the lower level annealing algorithm.

4. THE HYBRID POWER PLANT CASE STUDY

Bengkunat is located on the west coast Lampung with average wind speed in one year [5] as shown in Figure 2a. Clearness index and solar radiation in one year at Bengkunat [6] can be seen in figure 2b. Daily load profile for Bengkunat [7] with 594 customers and 139 kW peak load, as shown in Figure 3.



(a) (b)

Figure 2: (a) Wind speed [5] and (b) Clearness index and solar radiation [6] in Bengkunat

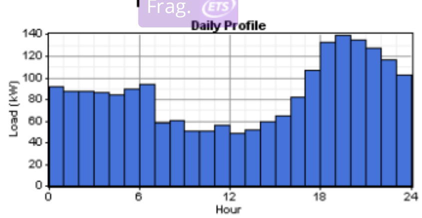
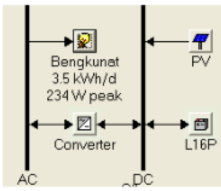


Figure 3: Bengkunat daily load profile

4.1 The Hybrid Power Plant Simulation

Figure 4a shows the solar home system model to be simulated with HOMER software and generation cost curve from the simulation results can be seen in Figure 4b. The hybrid power plant model consisting of PV modules, wind turbines, diesel generators 2 x 100 kW, inverter and batteries. Figure 5a shows the hybrid power plant model to be simulated with HOMER software and generation cost curve from the simulation results can be seen in Figure 5b.



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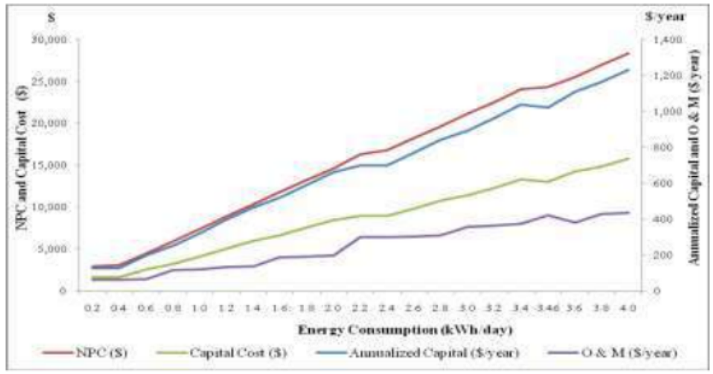

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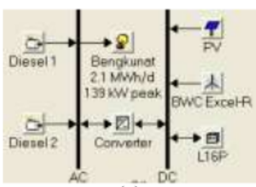
Figure 4: (a) The solar home system model and (b) Generation cost curve



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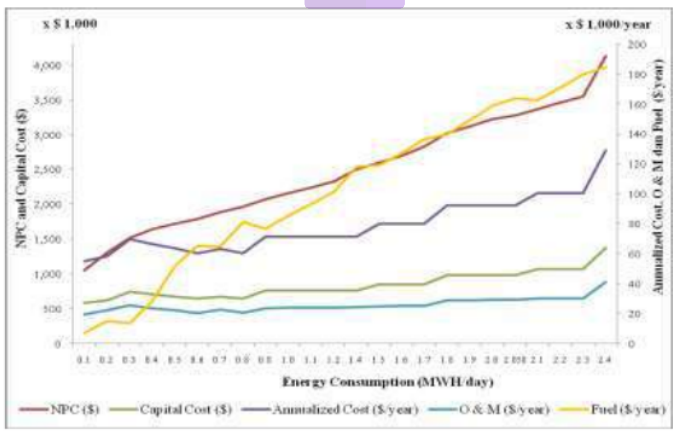

(b)

Figure 5: (a) The hybrid power plant model and (b) Generation cost curve

4.2 Distribution Network Model Simulation

The map obtained from Google Earth. This data is necessary for the location of power plant and demand points [8]. There are two configuration that performed in the simulation, the configuration without terrain features and with terrain features, such as road, forest and plantations.

ViPOR also require the components of a distribution network data consisting of 20 kV/400 V transformer with a capacity of 25 kVA, medium voltage wires LVTC 3 x35 + 25 mm^2 and low voltage wires A3C 70 mm^2 with a maximum length constraint is 700 meters.

5. DISTRIBUTION NETWORK OPTIMIZATION

5.1 Power Generation of The Hybrid Power Plant

The most optimal configuration of the hybrid power plant is a combination of PV modules, wind turbines and diesel power plant. Figure 6 shows the contribution of PV modules is 17%, wind turbines are 13% and diesel is 70% over the year, with excess electricity amounted to 42,973 kWh per year or 5.36% of total electricity production. Figure 7 shows the excess electricity occurred at 8:30 a.m. to 3:00 p.m., 48 batteries used were not sufficient to absorbed. At the same hour, the two diesel generators are not operating, the load is supplied by the PV modules and wind turbines. The COE is $ 0.409 per kWh, it isn't counting the distribution line. Fuel consumption is 204,823 liters per year, its saved 128,061 liters per year. If the load is only supplied by diesel power plant, 332,884 liters of fuel needed per year.

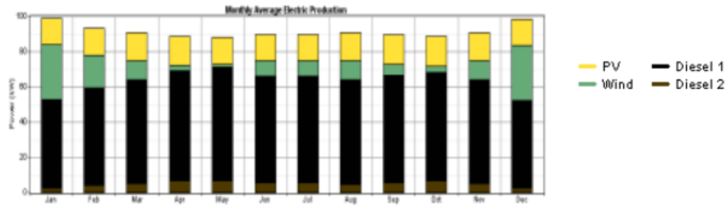

Figure 6: PV – Wind – Diesel Contribution

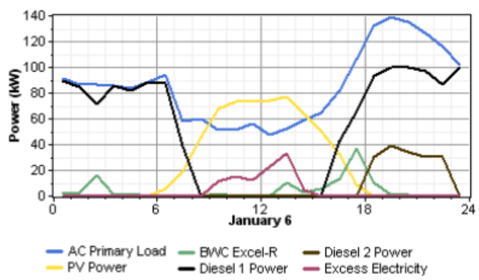

Figure 7: Load – PV, Wind and Diesel Power – Excess Electricity

5.2 Hybrid Power Plant Distribution Network

The simulation performed for the configuration of distribution network without terrain features and with terrain features.

5.2.1 Bengkunat without Terrain Features

The simulation results show the most optimum is a centralized distribution network with the NPC's total is $ 551,025. The length of low voltage line is 26,533 meters and medium voltage line is 4,662 meters, so the total length of distribution line is 31,195 meters. The hybrid power plant supply the average energy of 198.4 kWh per day. It takes seven transformers with maximum energy of each transformer is 35.4 kWh per day. The COE is $ 0.768 per kWh, its higher than the COE when distribution network cost is not taken into account ($ 0.409 kWh per day). Table 1 shows the NPC for distribution network is $ 235,080 and for power generation is $ 315,945, so that NPC's total is $ 551,025. With 594 loads, the NPC per load is $ 928.

Table 1: Cost components in Bengkunat power system without terrain consideration

Components	NPC ($)	Initial Capital Cost ($)	Total Annualized Cost ($/year)
Energy generation	315,945	94,839	27,513
Electricity distribution	235,080	19,.493	28,136
Total energy supply	551,025	28,.331	55,649
Per load	928	482	94

5.2.2 Bengkunat with Terrain Features

The most optimum result is a centralized system with the NPC total of $ 555,956. The length of LV line is 26,285 meters and the MV line is 5,770 meters, so the length total is 32,055 meters. It takes eight transformers with maximum energy supplied to each transformer 45.1 kWh per day. The COE is $ 0.777 per kWh. Table 2 shows the NPC for distribution network is $ 240,011 and for power generation is $ 315,945, so the NPC's total system is $ 555,956 and the NPC per load is $ 936.

Table 2: Cost components in Bengkunat power system with terrain consideration

Components	NPC ($)	Initial Capital Cost ($)	Total Annualized Cost ($/year)
Energy generation	315,945	94,839	27,513
Electricity distribution	240,011	195,598	28,768
Total energy supply	555,956	290,437	56,280
Per load	936	489	95

5.3 Distribution Network Optimization Analysis

5.3.1 Bengkunat Without Terrain Features and With Terrain Features Analysis

According to ViPOR, there are differences in MV line. This happens because in the configuration with terrain features, the forest, plantations and road increase the cost of distribution network. But this causes MV line length becomes longer (5,770 meters) than the configuration without terrain features (4,662 meters) and increasing the number of transformers from 7 to 8. The LV line length predicted (26,285 meters) shorter than the configuration without terrain features (26,553 meters), and the distribution line length for the configuration with terrain features (32,055 meters) longer than the other (31,195 meters). The NPC for distribution is $ 240,011 (the configuration without terrain features is $ 235,080), with the NPC's power generation amounted to $ 315,945, the NPC total system to be $ 555,956 (the configuration without terrain features is $ 551,025). So the NPC per load $ 936, larger than the configuration without terrain features($ 928). The COE is $ 0.770 per kWh, higher than the COE for the configuration without terrain features ($ 0.768 per kWh). Its much higher than the COE regardless of the distribution network ($ 0.409 per kWh). Comparison for both configurations can be seen in table 3.

Table 3: The hybrid power plant distribution network optimization results

Components	Without terrain features	With terrain features
Total NPC	$ 551,025	$ 555,956
Distribution NPC	$ 235,080	$ 240,011
NPC per load	$ 928	$ 936
Medium voltage line length	4,662 m	5,770 m
Low voltage line length	26,533 m	26,285 m
Total line length	31,195 m	32,055 m
Number of transformer	7	8
Maximum transformer load	35.4 kWh per hari	45.1 kWh per hari
COE	$ 0.768 per kWh	$ 0.770 per kWh

5.3.2 Bengkunat Hybrid Power Plant and Diesel Power Plant Analysis

Comparison of simulation results between the hybrid power plant distribution network model and the diesel power plant distribution network model can be seen in table 4. Its seen that the NPC system, power generation and per load of the hybrid power plant higher than the diesel power plant. But the NPC for distribution network is lower than diesel, this is happens because the 225 kVA diesel power plant transformer more expensive than the 25 kVA hybrid power plant transformer.

The hybrid power plant need 8 transformers with maximum energy supplied of each transformer is 45.1 kWh per day, while the diesel power plant use 5 transformers with maximum energy supplied of each transformer is 51.8 kWh per day. Difference occurs because the maximum length of the LV line for the hybrid power plant is 700 meters, while the diesel power plant is 1,000 meters. In the hybrid power plant simulation, with the average number of load 75 per transformer, the maximum power supplied by each transformer is 17.55 kW. With the resistance of LV line [9] is 0.468 Ω/km, the maximum voltage drop is 10 V, this is a consideration chosen 700 meters as the LV maximum length.

Table 4: Hybrid power plant and diesel power plant distribution network optimization results

Components	Hybrid power plant	Diesel power plant
Total NPC	$ 555,956	$ 505,493
Power generation NPC	$ 315,945	$ 251,861
Distribution NPC	$ 240,011	$ 253,632
NPC per load	$ 936	$ 851
Medium voltage line length	5,770 meters	4,724 meters
Low voltage line length	26,285 meters	27,011 meters
Total line length	32,055 meters	31,735 meters
Transformer	8	5
Maximum transformer load	45.1 kWh per day	51.8 kWh per day
Fuel consumption per year	204,823 liters	332,884 liters
COE	$ 0.770 per kWh	$ 0.739 per kWh

The hybrid power plant distribution network (32,055 meters) longer than the diesel (31,735 meters), both MV and LV. The hybrid power plant fuel consumption (204,823 liters per year) is more efficient (about 128,061 liters per year) than the diesel (332,884 liters per year). While the hybrid power plant COE is $ 0.770 per kWh, higher than the diesel ($ 0.739 per kWh).

From the simulation, it was found that transformer cost for ViPOR data input only step-down transformer with one capacity, so if requires a different transformer capacity, the simulation can not be done. The optimization based on the NPC value, not based on the voltage drop at the network, because ViPOR doesn't have outputs of voltage drop, power losses and power flow. Some of this is a shortage of ViPOR.

6. CONCLUSIONS

1. From the simulation, it was found that the distribution of the hybrid power plant in Bengkunat has a total length of 32,055 meters (5770 meters length of medium voltage and low voltage length of 26,285 meters), it takes 8 transformers with maximum energy supplied to each transformer is 45.1 kWh per day, and the NPC for distribution networka is $ 240,011.
2. Compared with a 2 x 100 kW diesel power plant (NPC = $ 505,493), the NPC value of the hybrid power plant is higher ($ 555,956) as well as its COE ($ 0.770 per kWh) is higher than diesel ($ 0.739 per kWh).
3. With 594 load, NPC hybrid power plant is higher ($ 936 per load) than diesel power plant ($ 851 per load).
4. The hybrid power plant will save 128,061 liters of fuel per year than diesel power plant. With the increasing of fuel prices, then by the sustainability of energy supplies in the future, the hybrid power plant is feasible to be applied in areas with enough wind and solar radiation resources such as at Bengkunat West Lampung.
5. From the simulation, it was found that ViPOR has several shortcomings such as :
   - Only step down transformers can be used for simulation, and only with one capacity. For a load configuration that requires a different transformer capacity, the simulation can not be done.
   - The optimization based on the NPC value, not based on the voltage drop at the network, because this software doesn't have outputs of the voltage drop, power losses and power flow.

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Confused You have used **an** in this sentence. You may need to use **a** instead.

Sp. This word is misspelled. Use a dictionary or spellchecker when you proofread your work.

Run-on This sentence may be a run-on sentence. Proofread it to see if it contains too many independent clauses or contains independent clauses that have been combined without conjunctions or punctuation. Look at the "Writer's Handbook" for advice about correcting run-on sentences.

Confused You have used **its** in this sentence. You may need to use **it's** instead.

Sp. This word is misspelled. Use a dictionary or spellchecker when you proofread your work.

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Wrong Form You may have used the wrong form of this word.

Article Error You may need to use an article before this word.

Frag. This sentence may be a fragment or may have incorrect punctuation. Proofread the sentence to be sure that it has correct punctuation and that it has an independent clause with a complete subject and predicate.

Article Error You may need to use an article before this word.

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Frag. This sentence may be a fragment or may have incorrect punctuation. Proofread the sentence to be sure that it has correct punctuation and that it has an independent clause with a complete subject and predicate.

Article Error You may need to use an article before this word.

Compound These two words should be written as one compound word.

Missing "," You may need to place a comma after this word.

PAGE 2

Article Error You may need to remove this article.

Proofread This part of the sentence contains a grammatical error or misspelled word that makes your meaning unclear.

Article Error You may need to use an article before this word.

P/V You have used the passive voice in this sentence. Depending upon what you wish to emphasize in the sentence, you may want to revise it using the active voice.

Proper Noun If this word is a proper noun, you need to capitalize it.

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Prep. You may be using the wrong preposition.

Proper Noun If this word is a proper noun, you need to capitalize it.

Confused You have a spelling mistake near the word **a** that makes **a** appear to be a confused-word error.

Sp. This word is misspelled. Use a dictionary or spellchecker when you proofread your work.

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PAGE 3

P/V You have used the passive voice in this sentence. Depending upon what you wish to emphasize in the sentence, you may want to revise it using the active voice.

Hyph. You may need to add a hyphen between these two words.

Missing "," You may need to place a comma after this word.

Prep. You may be using the wrong preposition.

Article Error You may need to use an article before this word. Consider using the article **the**.

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PAGE 4

Frag. This sentence may be a fragment or may have incorrect punctuation. Proofread the sentence to be sure that it has correct punctuation and that it has an independent clause with a complete subject and predicate.

Frag. This sentence may be a fragment or may have incorrect punctuation. Proofread the sentence to be sure that it has correct punctuation and that it has an independent clause with a complete subject and predicate.

S/V This subject and verb may not agree. Proofread the sentence to make sure the subject agrees with the verb.

Wrong Article You may have used the wrong article or pronoun. Proofread the sentence to make sure that the article or pronoun agrees with the word it describes.

Article Error You may need to use an article before this word.

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Article Error You may need to use an article before this word. Consider using the article **the**.

Missing "," You may need to place a comma after this word.

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PAGE 5

Run-on This sentence may be a run-on sentence. Proofread it to see if it contains too many independent clauses or contains independent clauses that have been combined without conjunctions or punctuation. Look at the "Writer's Handbook" for advice about correcting run-on sentences.

Proper Noun If this word is a proper noun, you need to capitalize it.

P/V You have used the passive voice in this sentence. Depending upon what you wish to emphasize in the sentence, you may want to revise it using the active voice.

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Missing "," You may need to place a comma after this word.

Confused You have used **its** in this sentence. You may need to use **it's** instead.

Missing Apos. Since this is a contraction, you need to use an apostrophe to form it.

P/V You have used the passive voice in this sentence. Depending upon what you wish to emphasize in the sentence, you may want to revise it using the active voice.

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Article Error You may need to use an article before this word.

Article Error You may need to remove this article.

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Verb This verb may be incorrect. Proofread the sentence to make sure you have used the correct form of the verb.

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Missing "," You may need to place a comma after this word.

Article Error You may need to use an article before this word.

Possessive You may need to use an apostrophe to show possession.

Article Error You may need to use an article before this word.

Missing "," You may need to place a comma after this word.

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