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ORIGINAL RESEARCH

A control strategy for hybrid energy source in backbone base transceiver station using artificial neural network: a case study of Penajam, Indonesia

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Abstract

Base transceiver station (BTS) is vital infrastructure in cellular communication. Without BTS, of course, communication cannot occur between cellular network users. Moreover, BTS is a BTS backbone that is a link between BTS. One of the problems with the BTS backbone is that energy sources. Without adequate energy for 24 h, of course, the supply of BTS cannot work. This is a problem in the BTS backbone located in Penajam, Indonesia. Therefore, it is necessary to regulate energy sources using the concept of hybrid energy sources (HES). In this study, the authors simulate the concept of HES by setting the energy source following the real site condition. The energy sources are the grid, diesel generators, and batteries. The control strategy is based on several policies that have been determined by the BTS operators. Due to the complexity of the rules, the strategy is realized into a binary rule. The binary rule is trained into a black box controller in an artificial neural network (ANN) to simplify the control system. From the simulation results obtained, the control system can stabilize energy distribution well, and there was an overshoot of 8.3% of the nominal value of the bus when switching switches to the diesel generator.

Keywords Artificial neural network · Base transceiver station · Control strategy · Hybrid energy system · Simulation

Abbreviations

ANN	Artificial neural network
BTS	Base transceiver station
VDC	Volt direct current
VAC	Volt alternating current
PV	Photovoltaic
SOC	State of charge
ATSMF	Automatic transfer source main failure
HES	Hybrid energy source

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Introduction

Base transceiver station or known as BTS is an infrastructure for telecommunications bridge that connects users wirelessly. The role of BTS is crucial for cell phone users because, without BTS, mobile phones will not have signals that can be used for communication, especially with the growing development of cell phone users which has implications for the increasing need for (BTS) [1]. Then, the role of BTS becomes a vital role so that the need for communication can be met.

However, BTS has another more important problem that is in supply energy. If BTS is installed in urban and rural areas, the electricity needs can be met [2]. This is because, in that region, there are still electrical connections that supply the population. With the electricity network, the BTS supply can be provided by taking from that grid network. However, if a BTS is installed in an area far from human activities and becomes a backbone BTS, it will be a problem. The problem comes because the BTS backbone is connecting links between districts with other districts without satellite with a chain system (link) [3, 4]. When the BTS backbone had a shutdown because of the lack of energy supply (because of limited electricity source), the other linked BTS will down too.

This problem occurs because of one big problem, that is, the limited BTS energy supply. This problem can happen because of two conditions. First, there is no electricity network at all in the BTS area, so the energy supply only comes from limited sources (photovoltaic, battery, wind turbine). The second condition is the presence of an electric energy source, but it is only active at certain hours, so the BTS is only active at certain hours. This will certainly have a very significant impact on the continuity of communication in the area to be linked. The most dangerous one is if the BTS is a backbone type BTS.

For solving this problem, several research ideas emerged. The idea is supplying BTS or some device with the concept of hybrid energy source (HES) [5–15]. With this concept, the BTS will be supplied with a variety of energy sources (hybrid), whether in the model of renewable energy (such as photovoltaic, wind turbines) or other power (such as diesel generators). Therefore, the continuity of BTS energy supply can be guaranteed with this strategy. For example, the study is carried out by Ahmed [16] in Nigeria. In this study, BTS is supplied with four energy sources, including wind turbines, photovoltaic (PV), batteries, and diesel generators. For solving this problem, the researchers use the HOMER software. Besides, there is also a similar study that is a research conducted by Anand [17]. In that study, researchers combined PV, battery, and diesel generators to supply BTS in India. The research was also solved using the HOMER software, whereas the research [18] located in the same country (India) also applied HES to BTS. It is just that distinguishes from previous studies. There is the addition of wind turbines to supply BTS. In another country, that is not much different from existing research [19–28].

Besides that, several studies not only show a HES to supply a BTS, but also compile a dispatching energy operation strategy. As in the research conducted by Kusakana [29], the purpose of this study is to optimize diesel and battery operations using mathematical programming. It was the same with the research conducted by Ajewole [30] that uses mathematical operations to maximize the use of PV and wind turbines with diesel. Also, research conducted by Aziz [5] and some research [31–33] develop a combination of HES control strategies by taking into several aspects. The first is the operational aspect of HES, and the second is the economic aspect.

However, from several studies related to HES for BTS energy supplied and the strategies, several studies are still focused on the primary energy with the continuous condition. This means that the main power (the grid) will only be disconnected in an emergency due to maintenance from the electricity provider or fault, not at certain hours, whereas in some regions, the characteristics of the primary energy source (grid) will only be active at certain hours to supply backbone BTS. Therefore, it is necessary strategies to dispatch energy so the BTS can be powered with continuity in this condition. Therefore, this strategy used might have a complex plan and have many states that must be passed before the system decides its strategic choice.

From some literature that discusses how energy can be dispatched, there will be many decision-makers to overcome control problems, as was done by Mohammed [34], who uses genetic algorithms. Then, the research conducted by Diemuodeke [35] used the multi-criteria decision-making algorithm, as well as several other studies [36–40] that utilize complex consideration functions. The consideration function is the “if” function with many branching decisions in managing energy distribution. This “if” method control model is more used by researchers than another control model. The reason why many researchers use this model is because the researchers do not need complicated algorithms on simple plant models or, more precisely, more comfortable to implement. However, the problem with this method is a decision that has many branches. Of course, this makes the system more complicated and more challenging to solve because a system must pass through many branches before it can make a decision [41]. This control model will also create confusion when there is a revision of the energy distribution management policy because too much “if” is used. By looking at some existing algorithms and trends in the development of intelligent control systems in energy management [42] that can summarize the complexity of control [41], ANN is one solution to overcome these problems.

Therefore, in this article, the researcher will propose a control model based on intelligence control using artificial neural network (ANN). The authors will modify and simulate this control model in one of the BTS located in Sepaku, Penajam, East Kalimantan, Indonesia. This site was chosen because, at this site, BTS is a backbone BTS. Furthermore, the problems at this site have conditions that have not been discussed by researchers before. The condition in question is energy supply discontinuity from the grid. The discontinuity of energy supply from the grid in question is that the grid is only active at certain hours. With these conditions, of course, the communication connection will be disrupted. By designing a system and environmental considerations following the real conditions, BTS will only be supplied by two energy sources and one energy storage. The two energy sources are grid and diesel generators, and the energy storage is batteries. The strategy of dispatching energy is compiling into a black box controller so that a controller can be made as simple as possible [43, 44]. This black box controller uses an artificial neural network (ANN), which has been designed with a set of conditions and several solution strategies. Several conditions are made by considering several policies that have been set by the BTS operators. The complex of the plans control strategy realized simplified in the binary rule model. ANN learns the binary rule so that it can take control as simple as possible. That way, the complexity problem can be solved, and the energy distribution at the BTS load remains continuous.

Case study and existing energy distribution description

In this study, the author takes the problem in the area of Sepaku, Penajam, East Kalimantan, Indonesia. This place was chosen because this site has a BTS backbone with energy supply discontinuity from the grid. Information on energy consumption and load profile is obtained from one cellular provider whose BTS backbone has energy problems. Also, the researcher conducted field surveys. From the results of a study conducted, the author received some information that is possible to use as preliminary information to solve. That information is about the available energy sources and load profiles that are shown in Table 1. The energy distribution scheme contained in the BTS Sepaku is shown in Fig. 1.

In the information that has been obtained by the author and is displayed in Table 1 and Fig. 1, it can be seen that the BTS is only supplied by one energy source. The energy source is a 16.5kVA grid with 220VAC voltage. There are loads that must be provided by the grid, namely load with AC voltage and load with DC voltage. First, for the DC voltage load a BTS radio with 1200 W power and 48VDC voltage is used. Second, for AC loads air conditioners and lamps with a total power of 3984VA and with a voltage of 220VAC are used. However, the problem with Penajam BTS is the limited supply of energy from the grid that cannot be supplied within 24 h. The grid only activated precisely 11 h 30 min, namely at 05.30 PM–06.00 AM. Given these problems, BTS will only serve usually during these hours. Therefore, this is important to be resolved.

Table 1 List of energy source and load profile in BTS Sepaku

Energy source		
1	Grid	16,500 VA
Load		
1	AC and utility	3984 VA
2	Radio (BTS) + fan	1440 W

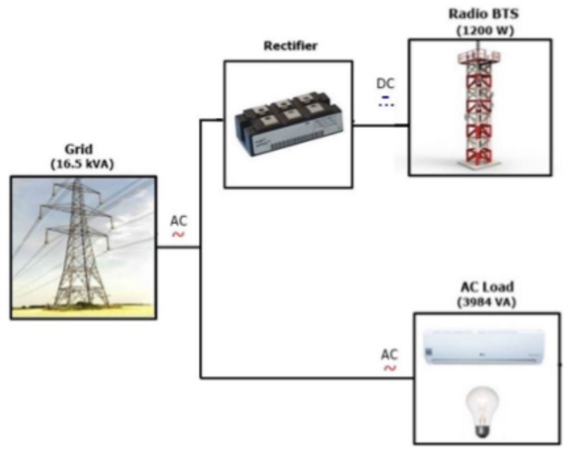


Fig. 1 Existing energy distribution in BTS Sepaku

Method and experimental setup

The proposed energy distribution architecture

To solve the problems found in BTS Penajam, authors have compiled several additional components, especially on energy sources, changing the architecture of energy distribution and designing energy dispatch strategies. The design will be simulated into MATLAB Simulink, and then, the results will be observed. The expected indication or target in the proposed system is on the sustainability of the energy supply at the BTS. Components that are added to the BTS are shown in Table 2.

In Table 2, the authors only included three possible energy sources for use. This is because field conditions do not allow photovoltaic (PV) or wind turbines to be installed. The reason is due to the limited area of sites and natural conditions that do not allow for installing those energy sources. By looking at the problems and conditions, the authors finally set the addition of a diesel generator as an alternative solution, so that the BTS can work outside hours when the grid is inactive. The authors add a 23,000 VA diesel

Table 2 Additional components of energy source and load profile in BTS Sepaku

Energy source		
1	Grid	16,500 VA
2	Diesel generator	23,000 VA
3	Battery	3840 W
Load		
1	AC and utility	3984 VA
2	Radio (BTS) + fan	W

generator, whereas the BTS total load is 5424 VA. However, because site conditions are far from the BTS operators, and it is expected that the designed system can save operating costs, the authors add batteries. Batteries installed have 2 V–800 Ah specifications with total power 3840 W. If observed, the installed battery has less power than the overall BTS load. However, this is indeed made in such a way. Cause the battery is only used to supply the main load, namely radio (BTS) and fan. This is done because the load is forbidden to die. As for the AC (air conditioner), load and the utility may die, so the load will not be supplied by batteries and will only be supplied by the grid or diesel generator. The energy distribution architecture scheme is shown in Fig. 2.

In Fig. 2, the system has two side voltages. The first side is the AC voltage with voltage source 220 VAC. On this side, there are two sources of energy and one AC load. The energy sources on the AC side include the grid (which is the primary source) and the diesel generator (which is the backup source). That two sources are connected with a panel that has functions to switch an AC voltage source (whether a grid or diesel generator system will supply the system). A control system will control this switching process. The load on the AC side is the air conditioner and other utilities such as lights.

The second side is the DC side. On this side, there are energy storage and a DC load (a BTS radio and a radio fan). On this side, there is also a bidirectional DC converter. The function of this converter is to control the battery charge and discharge process. Besides, this converter also serves to stabilize the supply voltage on the BTS radio. With this converter, the system does not make a voltage collapse due to interference [45, 46]. That interference, such as a grid power off or an interval of time waiting for power transfer (from the grid to the diesel generator). In this study, DC-link uses a 48 V voltage.

Proposed strategy description

The composition of the new energy distribution architecture and the addition of new components, of course, require a new set of strategies as well. The new plan is not only intended to allow energy to be appropriately distributed but also to ensure the continuity of energy supply in BTS, especially in DC Loads (BTS radio and BTS fan). Some of these strategies are as follows:

1. If the power capacity in a battery (SOC) is less than the minimum standard and the grid off, the diesel generator is turned on, the grid switches off, and the battery remains in a discharge condition (to keep the voltage stable). After a while, the diesel generator is active, the diesel generator switch is on, and the battery is in charge mode.
2. If the SOC battery is less than the minimum standard, and the grid is active, the system will see whether the diesel generator is in the previous condition when it is on. If it is on, the system will order to turn off the diesel generator. If the diesel reaches off condition (either in the condition before the grid is active, or after the diesel generator is turned off by the system), the system commands the diesel generator to switches off. The grid

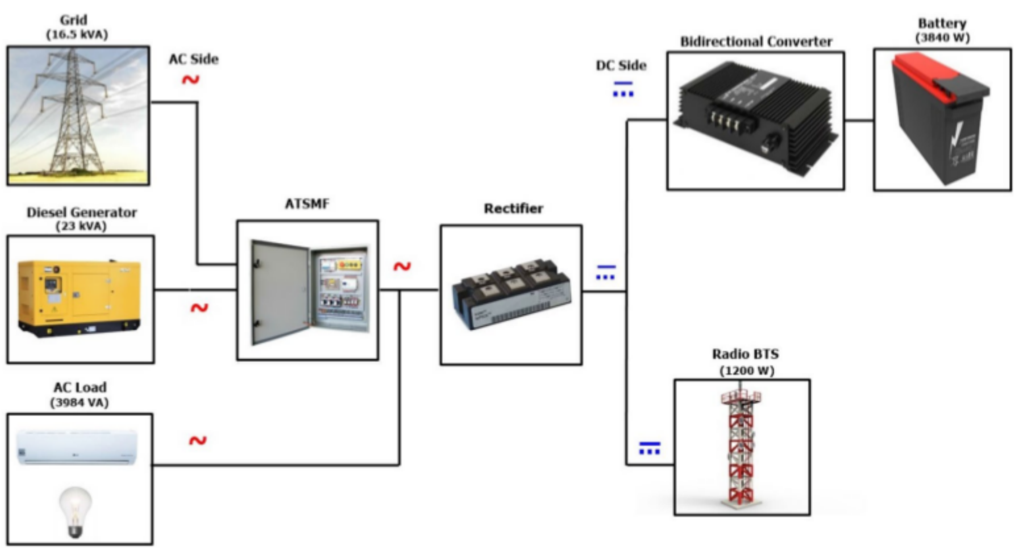


Fig. 2 Proposed energy distribution architecture scheme

switches turn to on and the battery change to charge condition.

3. If the SOC does not reach the minimum standard, the battery will remain in a state of discharge, grid switched off, and diesel generator switched off.
4. If during the charging condition, the battery has reached the upper limit (full), the system will change the battery condition from charging to discharging, and the switching grid is turned off.
5. If the charging state runs when the diesel generator is active, and then the battery reaches the upper limit (upper), the system will command the battery to be discharged. The system will control the diesel generator to turned off, and the diesel generator switch turns to off / disconnected.

From the explanation of the strategy to be used, it can be seen that several components can be used as input, and several components can be used as output. Inputs used include grid voltage (Volt_Grid), the voltage from the diesel generator (Volt_Genset), and battery capacity (SOC). The outputs used include triggers for the ignition of the diesel generator (Genset_Start), switches for the output voltage from the diesel generator to the main bus (Genset_In), switches for the output voltage from the grid (Grid_In), and commands for battery charge/discharge (Bat_CD). The input and output positions are used in the control process, for more details, as shown in Fig. 3

Rule table and data converting

Due to the complexity of the problem strategies used, the control strategy is prepared using binary rules rather than implemented in artificial neural networks (ANN). The purpose of using this way is to simplify programming rather than having to use the "if" function. So to facilitate the dispatching energy strategy, the overall plan contained in the

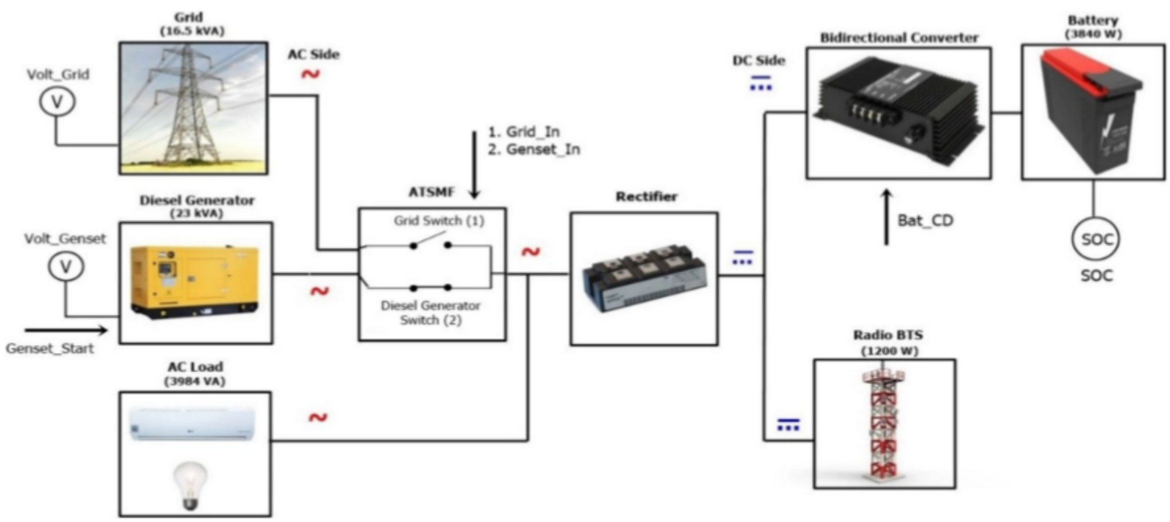


Fig. 3 Input and output position in energy distribution architecture

Table 3 Energy distribution strategies in binary rule strategy

Input			Output			
Volt_Genset	Volt_Grid	SOC	Genset_Start	Genset_In	Grid_In	Bat_CD
0	0	0	1	0	0	1
0	0	1	1	0	0	1
0	1	0	0	0	1	0
0	1	1	0	0	0	1
1	0	0	1	1	0	0
1	0	1	0	0	0	1
1	1	0	0	0	1	0
1	1	1	0	0	0	1

previous discussion is prepared using a binary rule as shown in Table 3.

In Table 3, there are three inputs, including the Volt_Genset (diesel generator voltage), Volt_Grid (grid voltage), and SOC (battery capacity), whereas for the output there are 4 of them, namely Genset_Start (command to turn on / turn off diesel generator), Genset_In (switch to connect the diesel generator to the mains supply network), Grid_In (switch to connect Grid to the main system), and finally Bat_CD (charge and discharge command for bidirectional converter).

To be compatible with ANN input, which is trained using binary rule, all system conditions, either input or output, must be converted to binary code. Therefore, the following explanation of some of the converting requirements is needed.

a. Input:
1. Volt_Grid, if there is a voltage or has 220 VAC (active) in the grid, it gives a value of 1. Then, if there is no voltage (not active) or has 0 VAC in the grid, it gives value 0.
2. Volt_Genset, if there is a voltage or has 220 VAC (active) in diesel generator, it gives a value of 1. Then, if there is no voltage (not active) or has 0 VAC in diesel generator, it gives value 0.
3. For SOC, if the SOC is above 60% (in this case as the minimum voltage for safely to be discharged), it gives value 1. But, if the SOC is under 60%, which indicates that the battery is in the range condition that needs a quick charge, it gives value 0.

b. Output:
1. For the Genset_Start is 1 (trigger command), this is the command to start the generator. If Genset_Start is 0, this is the command to turn off the generator.
2. For Grid_In, if the value is 1, then this shows that the system ordered to connect the grid to the system. If the value is 0, then the system instructs to disconnect the grid from the system.
3. For Genset_In, if the value is 1, then this shows that the system ordered to connect the diesel generator to the system. If the value is 0, then the system instructs to disconnect the diesel generator from the system.
4. Because the process of charge and discharge batteries is controlled by the system, this process also will be commanded by the system. If Bat_CD has a value of 1 (trigger command), then this is a command to discharge. If Bat_CD has a value of 0, then this is the command to charge. By using a bidirectional converter, then it can be controlled easily.

Neural network design

To implement the binary rules contained in the previous section, ANN is used. In this study, the ANN used has a network structure that is shown in Fig. 4. ANN structure design uses three inputs, one hidden layer with three inputs and four outputs. ANN structure is shown in Table 4, and for the result of accuracy can be seen in Fig. 5.

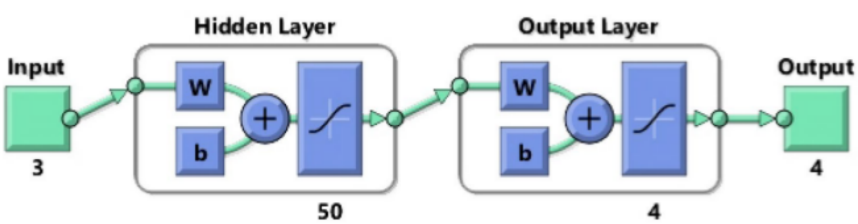
From Table 4, it can be seen related to the ANN structure used by researchers. For input, there are three, namely Volt_Grid, Volt_Genset, and SOC, while the hidden layer used is 1 with 50 neurons. Activation used in the hidden layer is sigmoid. The output layer consists of 4, namely Genset_Start, Genset_In, Grid_In, and Bat_CD. The activation used is also the same as in the hidden layer, which uses sigmoid activation.

For the training process, ANN will be trained using the data contained in Table 3. The data used are the overall data provided in the table, so there are eight rows of data that become training data. For testing data used in this training, the phase is the overall data or data used in the previous training. The reason why we use the same data in the training process with the testing process is that the target of the trained ANN model is to imitate the rules set by the user, not to predict the rules. Therefore, the output between trained data must be following the tested data. The results of the training process are shown in Fig. 3. The results obtained indicate that ANN has perfect training correlation, which is equal to R = 1 for each session.

Simulation setup

To simulate the proposed system and strategy, researchers will use Simulink MATLAB simulation software. The overall proposed system circuit is shown in Fig. 6. In Fig. 6, it can be seen that the system consists of three energy sources. The first energy source is the grid, the second is the generator set or emergency diesel, and the third is the battery with

Fig. 4 ANN structure used



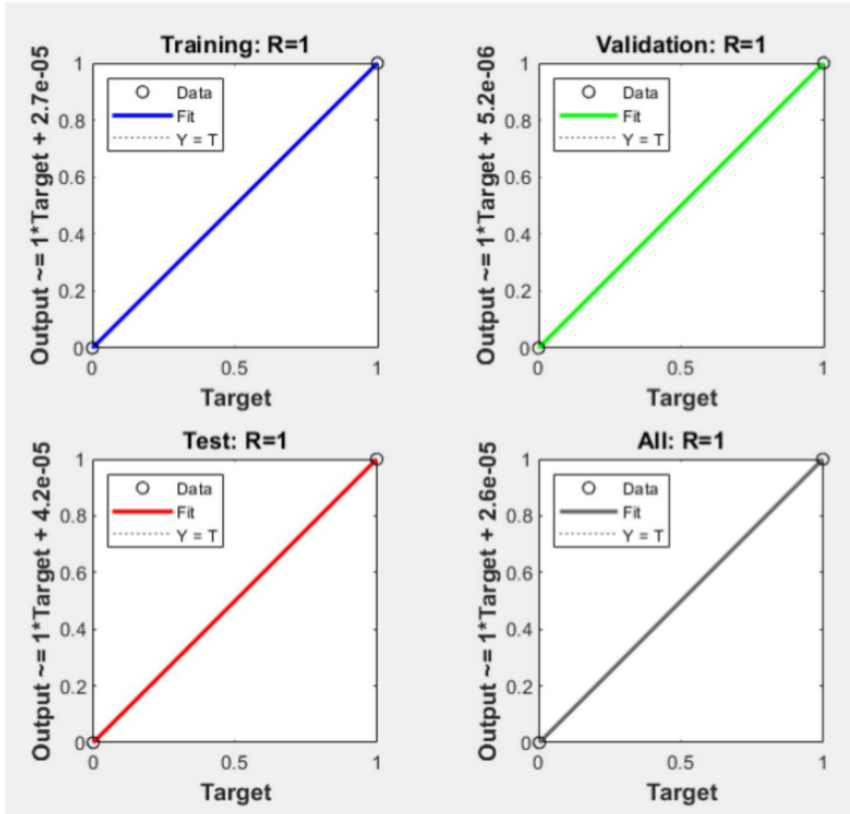


Fig. 5 Accuracy results in training and testing process in an artificial neural network

Table 4 Parameter information in ANN structure used

Type	Parameter	Information
Input	3	1. Volt_Genset 2. Volt_Grid 3.SOC
Hidden Layer	Neuron: 50 Activation: Sigmoid	
Output Layer	Neuron: 4 Activation: Sigmoid	1.Genset_Start 2.Genset_In 3.Grid_In 4.Bat_CD

a bidirectional converter. Two energy sources, namely grid and diesel, are installed with a switch that functions as a diversion of resources. This needs to be installed because if two energy sources that have different phases are combined just like that, then this will cause damage to one energy source and cause the energy source to be out of sync. This will make the electronic devices connected to the power source disturbed or even damaged. Therefore, the two energy sources in this simulation are separated by a switch. The system is tasked to control this switch so that there is no direct connection between the two energy sources at one time. After entering the switch, the two energy sources are converted into DC voltage with a voltage of 48 V (bus voltage).

In the next energy source, namely the battery, this energy source is regulated by the bidirectional converter. The task of the bidirectional converter is to control when the battery must be charging and when the battery must discharge. By using a bidirectional converter, the battery discharging voltage and the battery charging current can be controlled. So this is one of the advantages of using this converter in HES (hybrid energy source) to sustain voltage stability. In Fig. 6, the discharge voltage is set to be stable at 48 V (according to the nominal bus voltage), and the maximum charge current is 5A. Because the design of the bidirectional converter has tasked to controlling voltage and current, the bidirectional converter uses the PID controller.

Figure 7 shows the control system used in this study. In the previous explanation, it has been mentioned that the control principle used is based on binary rule controllers. Therefore, to realize this, all signals must be converted to binary values before entering the control system. Figure 7

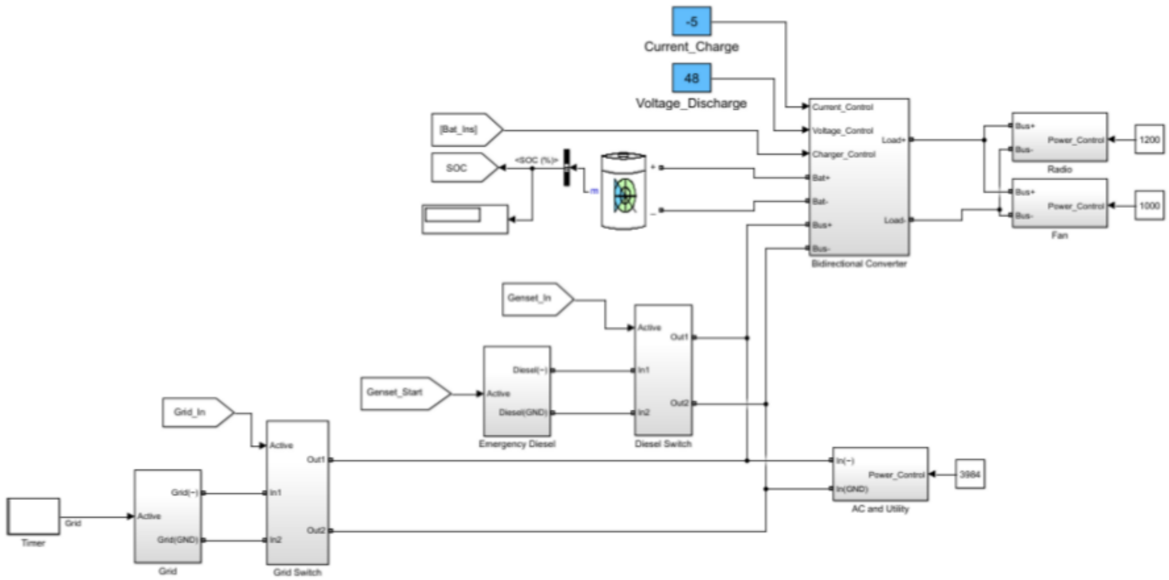


Fig. 6 Total simulation

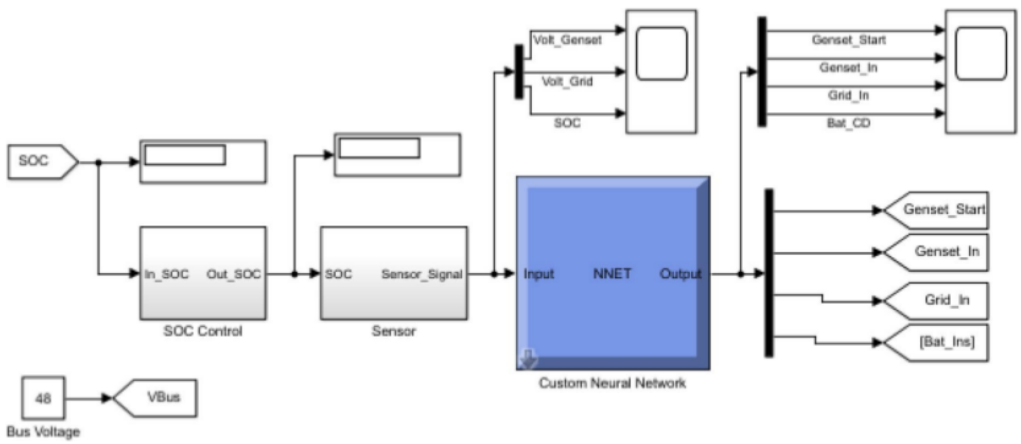


Fig. 7 Control system by using ANN

shows that there are two blocks in the form of SOC control and sensor. The SOC control block functions as a SOC condition converter to binary values. This conversion is based on the battery's upper and lower limit techniques. If the battery is in 100% condition, the SOC will give a value of 1, which means the battery is ready to enter in discharge mode. But if the battery condition goes from 100 to 61% and then reaches 60% (lower limit), then the SOC will give a value of 0. This value indicates that the battery needs energy for the charging process. After the charging process is carried out, the SOC value rises, starting from 60% (the lower limit) to 100% (the upper limit). When the process goes up, the SOC will still be 0. But after reaching 100%, the SOC will be 1, while the sensor block is a conversion block for the other two inputs. The different other inputs are volt_genset (voltage from the generator set) and also volt_grid (voltage from the grid). Because voltage is not a binary value, the conversion process is carried out. So when there is a voltage source (voltage > 48 VDC), the input will give a value of 1. If it does not detect a voltage (voltage ≤ 0), it will give a value of 0.

The output of the control system has also been adjusted to the planned plant, i.e., there are four outputs. Genset_Start, Genset_In, Grid_In, and Bat_CD. Because the output of ANN is in the form of binary values, the conversion process to binary values is not carried out. After all the simulation blocks have been arranged, the simulation is run, and the results are observed.

Testing scenario

The testing of this system will be carried out by running the system within one day (24 h) of full loading. With the conditions described in the previous section, all conditions and system responses will be observed to find out how is the impact of the given rule to the system to maintain the voltage stability. Some data taken are input from the control system, control system output, and bus voltage. For the simulation of loading, all loads are considered to work optimally.

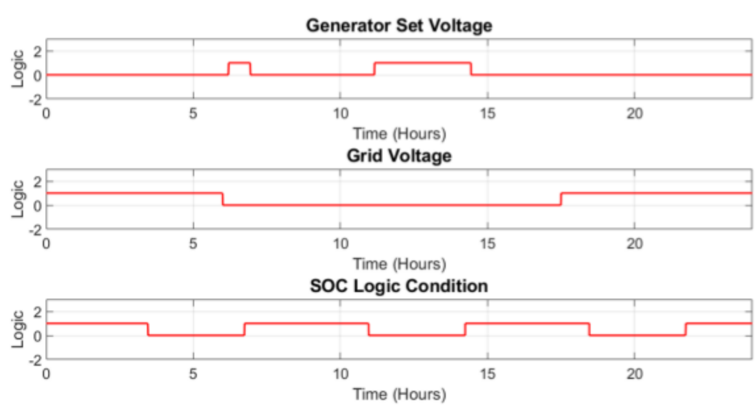
Result and discussion

Figure 8 shows the signals obtained during the simulation process. Figure 8 shows the input of the control system used in this study. Following the previous explanation, there are three input signals used. These signals include voltage signals on the generator set, voltage signals on the grid, and SOC signals. The response contained in Fig. 8 is the result of the simulation response that occurs in one day cycle (24 h). From this response, it appears that the grid is only active at 05.30 PM–06:00 AM. Between these times, the grid is turned off. In the previous column, there is also a generator voltage signal column. When the signal logic is 1, then this signal indicates that the generator set is active. If the generator set has logic 0, then this means that the generator set is off. The next column is the SOC column or an indication of the amount of energy left in the battery. When SOC is 1, this signal indicates that the battery is still in a safe condition for discharge. If the SOC is 0, this shows that the battery must immediately enter charge mode. In this simulation, the author uses an upper limit of 100% (maximum charge limit) and a lower limit of 60% (maximum discharge limit).

When it sees the results of the response to the input of the control system, the generator voltage is not active continuously. The voltage generator is only active when the SOC is in a state of need to charge and when the grid is inactive. This is according to the expected system design that as long as the battery has sufficient energy (SOC) conditions, the battery will continue to discharge to the lowest SOC. So if the SOC cycle is 100% (the upper limit) up to 60% (the lower limit), then the SOC signal will be 1. But when the SOC has reached 60%, then it goes into charge mode, and the SOC reaches 100%, so long as that (the process charging) the SOC signal will be 0. Meanwhile, to be able to see how the response of the system that has been formed to changes in energy sources can be seen in Fig. 10.

In Fig. 9, there are four outputs. Among the outputs are the generator start command (Gen_Start), the generator switch command (Gen_In), the grid switch command (Grid_In), and finally the battery command (Bat_Ins). The results of the control system response show that the system has worked well. This is shown in response to each output that is by the scenario. The first is related to the grid. In the plan shown in Table 3, the system will order the battery to charge and transfer the main energy transfer to the load from the grid if the SOC signal is 0 and the grid is still active. From the results in Fig. 8 (SOC conditions) and Fig. 9 (in the grid switch command and battery command), the system has successfully performed its tasks according to the rules (time between 3 and 6 h). The second is related to the condition if the grid is inactive, and the battery's SOC is logic 0 (requires charging). If this condition occurs, the system must order the battery to remain in the discharge condition (logic 1) for a while until the generator is active and entered as the main source of BTS load. This needs to be done because the generator, when the system is ordered to start, the generator

Fig. 8 Input response



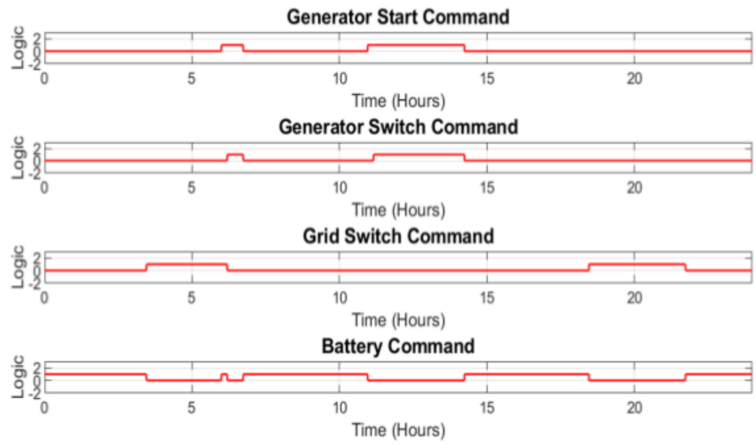


Fig. 9 Output response

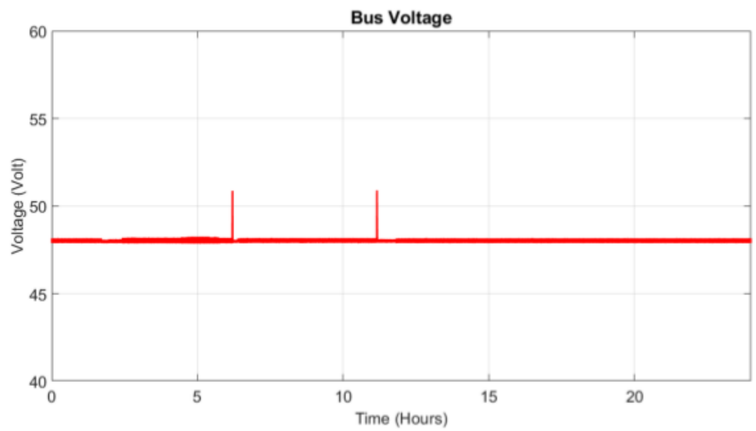


Fig. 10 Bus voltage response

takes time to reach 48 V or nominal bus voltage. When sometimes the generator voltage has reached 48 V, the generator voltage will be switched into the system as the main energy source until the SOC of the battery reaches logic 1, or the condition of the battery can change to the discharge logic. This is shown in Fig. 9, namely at ± 6 h (where when the grid is active, but SOC still needs to charge). Bus voltage response is shown in Fig. 10.

In Fig. 10, it can be seen that the bus has been successfully stabilized at 48 V at the time of transfer of the main energy source. However, at certain hours, voltage overshoot occurs. Overshoot voltage that occurs has a value of 52 V or an increase of 8.3% from 48 V. This phenomenon occurs because, at that time, there was a transfer of energy sources to the generator set. This transfer occurs twice, namely at vulnerable times 5–6 h and 11–12 h. But overshoot only occurs when the generator set voltage is connected to the load, while when other energy sources are connected/disconnected from the load, the voltage on the bust does not experience overshoot.

Conclusion

From the simulation results related to the energy distribution strategy at the backbone base transceiver station (BTS) in Penajam, Indonesia, several conclusions can be concluded. The first is related to the strategy used. In this study, the authors formulate a strategy by simplifying control using binary rules. By using an artificial neural network (ANN), the binary rule is compiled and implemented into a simulation. The results obtained indicate that ANN can complete its tasks following the policies and strategies of BTS operators. The second is related to the stability results, which are the main target in the problems of the hybrid energy system (HES). From the results of implementing controls, the system can be stable in 48VDC. This stability occurs in all lines of transition or transfer of renewable energy sources. But from the results, it turns out there are still overshoot problems that occur due to the diesel generator transition. Overshoot that occurs is 4 V from the nominal value of the bus voltage (48 V) or 8.3%.

Therefore, for further research, the researcher suggests several things. The first is related to additional strategies by adding renewable energy sources such as PV or windturbine. Second, consider the amount of fuel in diesel fuel as input in this strategy. This development strategy is related to economic dispatch to reduce diesel operating costs as optimal as possible.

4 Compliance with ethical standards

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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