Optimal Variable Speed Control of BLDC Diesel Generator to Enhance Fuel Efficiency

Bakhtiar Sudibyo
Departement of Electrical Engineering
Institut Teknologi Sepuluh Nopember
Surabaya, Indonesia
6022222012@student.its.ac.id

Heri Suryoatmojo
Departement of Electrical Engineering
Institut Teknologi Sepuluh Nopember
Surabaya, Indonesia
Suryomgt@ee.its.ac.id

Daniar Fahmi
Departement of Electrical Engineering
Institut Teknologi Sepuluh Nopember
Surabaya, Indonesia
Daniarfahmi@ee.its.ac.id

***Abstract*— The growing adoption of renewable energy technologies still faces challenges such as instability, intermittent, and limited energy storage capacity. Diesel engine generators, known for their stability and reliability, remain essential as primary or backup power sources, especially in remote areas. However, conventional diesel generators operating at constant speed are inefficient in fuel consumption and produce high emissions. This study investigates the implementation of a variable-speed diesel generator system using a BLDC (Brushless Direct Current) generator controlled by a fuzzy logic-based controller (FLC). The proposed system adjusts engine speed and the duty cycle of the converter to optimize fuel efficiency while maintaining voltage and frequency stability. Simulation results demonstrate that the system reduces fuel consumption by up to 7.6% (0.86 liters/hour) for a 100 kW generator. Additionally, the FLC effectively stabilizes voltage and frequency during load changes and finally enhancing overall system performance.**

Keywords*— *BLDC, fuzzy logic, variable speeds

I. Introduction

A diesel generator, also known as a diesel genset, is a power generation machine that uses a diesel engine as its power source. Diesel generators are widely used as backup or primary power sources in various applications, such as hospitals, industries, and remote areas without access to the electrical grid [1]. Diesel generators typically operate at a constant speed; however, integrating variable-speed technology can enhance their performance and flexibility. This combination is known as a "Diesel Generator Variable Speed" (DGVS).

Variable-speed generators provide key advantages, including reduced emissions. The generator operates at lower speeds during low loads, resulting in lower emissions and reduced air pollution [2]. These generators also offer high flexibility as they can be integrated with intermittent renewable energy sources like wind and solar power, as they can adjust to power fluctuations. The sizing of generators is frequently based on peak load values to preventing overloads. In remote areas, generators provide power for extended periods of time at levels below peak load. Consequently, variable speed operation will significantly reduce fuel consumption during periods of low load demand.

Several studies on variable speed generators (VSG) have been conducted. In [3] remote areas with relatively small consumers, diesel generators are commonly used to produce AC power with constant voltage and frequency. Nayer et al have modelled a variable speed diesel generator (VSDG) using a Doubly-Fed Induction Generator for application in stand-alone mode. The model produces optimal power with good power quality using a stator flux-oriented vector control algorithm. In another article [4], Nayer et al. also proposed a control strategy with sensorless method and active filter so that the diesel engine can work below or above the synchronization speed.

Article [5] utilizes the Adaptive Inertia Weight Particle Swarm Optimization (AIWPSO) algorithm to determine Specific Fuel Consumption (SFC), yielding more optimal results compared to conventional PSO algorithms. The system also incorporates an AC/DC/AC conversion process using a combination of a Vienna rectifier and an inverter, controlled with a hysteresis controller to regulate frequency. Similarly, the AC/DC/AC system in [6] integrates power electronic devices, including a rectifier, boost converter, and inverter, to regulate voltage and frequency through the application of a Fuzzy Logic Controller (FLC). Simulation results demonstrate that the FLC significantly enhances system performance compared to a PI controller.

The control system is an important part in the success of VSDG. Article [7] describes in detail the application of PI controllers to the rotor-side and load-side converters. The addition of solar panels connected through DC-DC Boost converters with an improved P&O algorithm, the system can supply power to the load uninterrupted with minimal or even zero fuel consumption. A simpler VSDG system was demonstrated by [8] with the application of fuzzy control through the converter. Simulation results show that the application of fuzzy improves fuel consumption efficiency by up to 21% when compared to PI control. Article [9] uses an incremental algorithm to find the optimal point of control operation of the VSDG system that can reduce fuel consumption specifically. This algorithm is an adaptation of the wind turbine energy conversion system which is then developed to prevent peak torque during the incremental step when there is a change in the reference speed. This control can shorten the transient state of the output voltage when there is a change in the load.

A Brushless Direct Current (BLDC) generator is a type of electrical generator that uses a BLDC motor as its driving source. BLDC generators offer several advantages over conventional generators, such as higher efficiency than conventional generators. because there is no mechanical friction from brushes and commutators [10]. BLDC generators are more reliable because they lack components that are prone to wear, such as brushes and commutators. BLDC generators are also more compact than conventional generators because they do not require a gearbox [11]. Its trapezoidal waveform back-emf and the rectangular current

 How to cite: Sudibyo, B., Suryoatmojo, H., Fahmi, D., (2025). Optimal Variable Speed Control of BLDC Diesel Generator to Enhance Fuel Efficiency. *JAREE (Journal on Advanced Research in Electrical Engineering), 9(2).*

waveform combination increase power density up to 15% and ensure constant power [12].

The BLDC generator is considered a new type of generator compared to more commonly used generators such as permanent magnet synchronous generators. This paper is proposed for an effective control system based on fuzzy logic controller (FLC) as a means of regulating the speed of the BLDC diesel generator, with the objective of achieving optimal speed in variable speed mode. Additionally, the paper presents a proposal for a control system based on duty cycle control of the power converter, with the aim of maintaining the robustness and stability of voltage and power frequency while the generator is running in variable speed operation.

II. Materials and Methods

This section covers the methodology of the research such as modelling BLDC diesel generator system and design of FLC.

A. Diesel Engine Modelling

A diesel engine transforms chemical energy into mechanical energy, which drives the rotor of an induction generator to generate electricity. In conventional diesel generators, the engine typically operates at a nearly constant speed, but it is also capable of variable-speed operation. For this, the speed of the diesel generator can be regulated using an actuator. Adjusting fuel injection at specific speeds allows for precise control of mechanical torque at the rotating shaft. The fuel injection and engine speed are determined based on a fuel consumption versus load power map, obtained through field tests of the diesel engine and induction generator [3].

The speed controller will compare the value of actual speed (ω_m) and reference speed (ω_{ref}). Each load has its optimal speed for efficiency fuel consumption. So the optimal reference speed must be difference for each load demand. This data can be obtained from tracking load demand trough lookup table setting. Setting lookup table is based from universal characteristic of diesel engine map in figure 1.

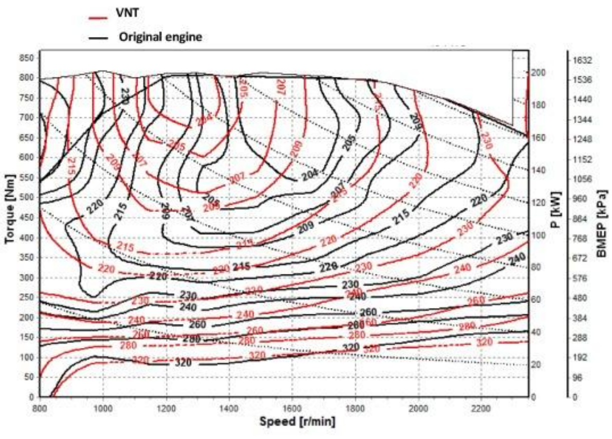

Fig. 1. Universal characteristic of diesel engine*[13]*

Figure 1 show the mapping of diesel engine fuel efficiency (g/kWh) in term speed and power. For example, in same power 40 kW. Diesel engine in 1500 rpm speed operation has fuel efficiency 220 g/ kWh and in 1100 rpm is 214 g/kWh. Furthermore, variable speeds operation can reduce diesel engine fuel consumption.

The engine speed is controlled by an actuator responsible for fuel injection. The control signal determines the amount of injected fuel mass which affects the engine torque (T_m). Fuel consumption is obtained from the electronic governor

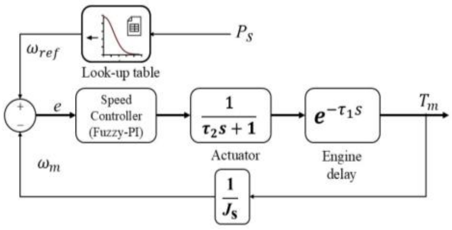

Fig. 2. Model of speed control loop of a diesel engine

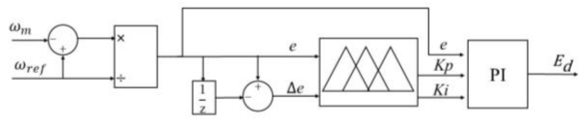

Fig. 3. Diesel engine speed controller diagram

system, while the actual speed is measured by a gear sensor. The speed control block consists of a speed regulator, an algorithm for determining minimum fuel consumption, and a section for identifying load power. The loop model can be seen in Figure 2.

The engine speed control mechanism is quite similar for both constant and variable speed operations. The parameters consist of maximum torque, moment of inertia, and governor delay. J_s is the total moment of inertia, and the engine torque T_m. engine torque must be same or than load torque and friction torque to keep generator rotate in certain speed.

The actuator time constant, τ_2, is highly dependent on the type of injection. For direct injection, the time constant is around 0.1 milliseconds, while for indirect injection, the time constant can reach up to 0.1 seconds. For small-sized engines, the time constant is around 0.5 seconds. The diesel engine delay time can be calculated using equation (1).

$$\tau_1 = \frac{60S_T}{2Nn} + \frac{60}{4N} \tag{1}$$

Where S_T is the number of strokes, N is the engine speed in RPM, and Nn is the number of cylinders in the diesel engine [9]. The diesel engine parameters are shown in table I below.

TABLE I. DIESEL ENGINE PARAMETERS

Parameters	Value
Actuator time constant (τ_2)	0.1
Number of stroke (S_T)	4
Number of cylinders (Nn)	4
Rating speed (N)	1500 RPM
Moment inertia (J_s)	4.4 kg.m^2

The actuator is regulated by the speed controller to get engine speed that needed. The speed controller of the system uses fuzzy-PI combination. Input fuzzy consist of error (e) and delta error (Δe). Then the rule base will make decision for output fuzzy where these outputs are K_p and K_i value for PI controller to control actuator. Diagram of the speed controller is shown in figure 3.

Membership functions for speed controller is show figure 4. Input membership functions consist of NL (Negative Large), NM (Negative medium), NS (Negative Small), Z (Zero), PS (Positive Small), PM (Positive Medium), and PL (Positive Large) for variable inputs. The output membership functions also consist of seven membership functions consisting of ZE (Zero), VS (Very Small), MS (Medium Small), ME (Medium), MB (Medium Big), VB (Very Big), and VL

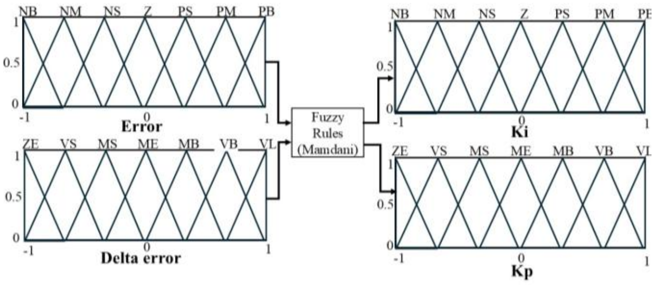

Fig. 4. Fuzzy membership function for speed controller

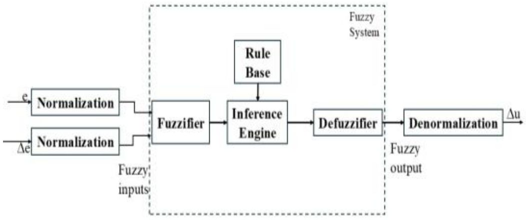

Fig. 5. General schematic fuzzy logic controller

(Very Large). And its rule based for engine speed controller is shown in table II.

TABLE II. FUZZY RULE-BASED FOR ENGINE SPEED CONTROLLER

Δe \ e (Ki Kp)	NB	NM	NS	ZO	PS	PM	PB
NB	VL ZE	VL ZE	VB VS	VB VS	VB MS	ME ME	ME ME
NM	VL ZE	VL ZE	VB VS	MB MS	MB MS	ME ME	MS MS
NS	VB ZE	VB VS	VB MS	MB MS	ME ME	MS MB	MS MS
ZO	VB VS	VB VS	VB MS	ME ME	MS MB	VS VB	VS VB
PS	MB VS	MB MS	ME ME	MS MB	MS MB	VS VB	VS VL
PM	VS ME	MB ME	ME MB	MS MB	VS VB	VS VL	ZE VL
PB	ME ME	ME ME	VS MB	VS VB	VS VB	ZE VL	ZE VL

B. BLDC Generator

BLDC stands for Brushless Direct Current. It refers to a DC generator design that does not require brushes and a commutator to provide magnetic flux, as is typically the case with DC machines. A BLDC generator is a permanent magnet generator with permanent magnets in its rotor. The rotation of the rotor, which contains permanent magnets, induces a flux change in the stator windings. The stator is made up of laminated steel to reduce eddy current effects[14].

The parameter of BLDC generator is shown as followed.

TABLE III. BLDC GENERATOR PARAMETERS

Parameter	Value
Power	125 kVA
Power	100 kW
Rated speed	1500 rpm
Standar voltage	400 V
Frequency	50 Hz
Stator resistance	0.18 Ω
Inductance	0.000835 H

C. Power Converter

The proposed system uses full-scale converter to maintain constant voltage for load where voltage stator is

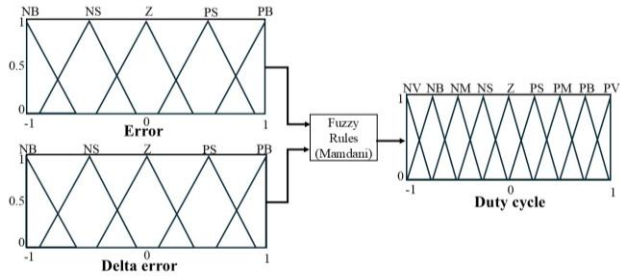

Fig. 6. Fuzzy membership function for FLC duty cycle

changing in variable speed mode. BLDC generator rectifier connected with buck-boost converter in DC link and next DC link will transfer power to inverter to product AC power for load.

1) Buck-Boost Converter

The Buck-boost converter parameter that is used in this system can be seen on table IV.

TABLE IV. BUCK-BOOST CONVERTER PARAMETERS

Parameter	Value
Output voltage	650 V
Voltage ripple	30 V
PWM frequency	20 kHz
Inductor	4.1 mH
Capacitor	420 µF

Based on the principle that the voltage across the inductor must be zero over one cycle, the relationship between the input voltage Vin and the output voltage V_{out} can be derived as shown in equation (2).

$$V_{out}=\frac{d_1}{1-d_2}V_{in} \quad (2)$$

This equation for non-inverting buck-boost converter with two switching components. However, when $d_1 = d_2 = d$. the circuit will become remarkably similar to a conventional buck-boost converter.[15]

The general schematic of the FLC is shown in Figure 5. The FLC receives two inputs, named error and delta error. The error value represents the difference between the converters' output voltage and the reference voltage, as expressed in the equation (3).

$$e(k)=V_{out}(k)-V_{ref}(k) \quad (3)$$

Meanwhile, delta error is the difference between the current error value and the previous.

$$\Delta e(k)=e(k)-e(k\text{-}1) \quad (4)$$

All of these value will be define to several membership function. Rule base will compare error and delta error for making decision of output value.

The membership functions of the inputs and outputs FLC is shown in figure 6. Five terms of Triangular input membership functions like in fuzzy speed controller is chosen for easier computation. And for output triangular membership function are nine terms. Input variable consist of negative big (NB), negative small (NS), zero (Z), positive small (PS), and positive big (PB). And output variable consists of negative very big (NV), negative big (NB), negative moderate (NM), negative small (NS), zero (Z), positive small (PS), positive moderate (PM), positive big (PB), and positive very big (PV). Rules based for duty cycle controller is shown in table V.

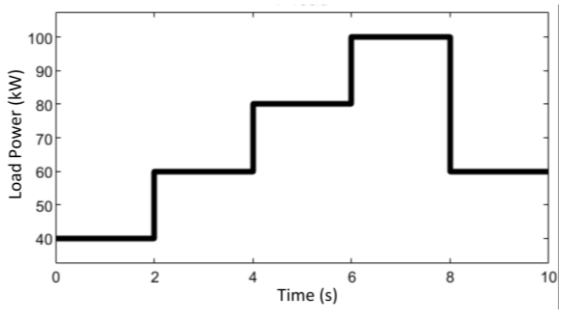

Fig. 7. Load modelling

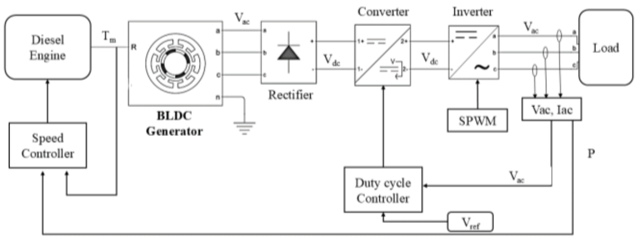

Fig. 8. Block diagram of variable speeds BLDC diesel generator

TABLE V. FUZZY RULES-BASED FOR DUTY CYCLE CONTROLLER

Δe \ e	**NB**	**NS**	**Z**	**PS**	**PB**
NB	NV	NV	NV	NB	Z
NS	NV	NM	NS	Z	PB
Z	NV	NS	Z	PS	PV
PS	NB	Z	PS	PM	PV
PB	Z	PB	PV	PV	PV

2) *Inverter*

On the load side of the converter, there is a three-phase inverter device, commonly known as Voltage Source Inverter (VSI). The inverter functions are to convert DC power from the DC link into three-phase AC power with insulated gate bipolar transistors (IGBT) looks the switching device.

Inverter is controlled using Sinusoidal pulse wide modulation (SPWM). This is a closed loop PWM modulation type that is most commonly used for control multilevel inverters. A sinusoidal reference waveform is compared to a triangular carrier waveform to produce switching signals for the power semiconductors in inverter modules. Specification of the inverter device and control is shown on table VI.

TABLE VI. INVERTER PARAMETERS

Specification	Value
PWM frequency	5000 Hz
Inverter frequency	50 Hz
Modulation index	0.8
Inductor filter (L)	0.13 mH
Capacitor filter (C)	780 µF

The variable speed generator system produces electrical power with an inconsistent frequency. After passing through the rectifier and DC link, SPWM sends unipolar switching signals to control the VSI to generate AC voltage and current. The VSI is connected to the load through an L-C filter to provide power with a constant voltage and frequency, even though the output from the generator fluctuates.

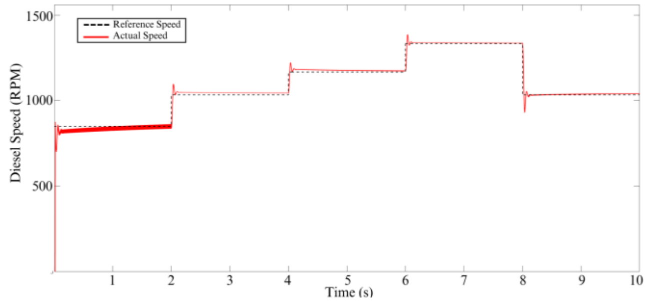

Fig. 9. Simulation result of diesel engine speed with load change

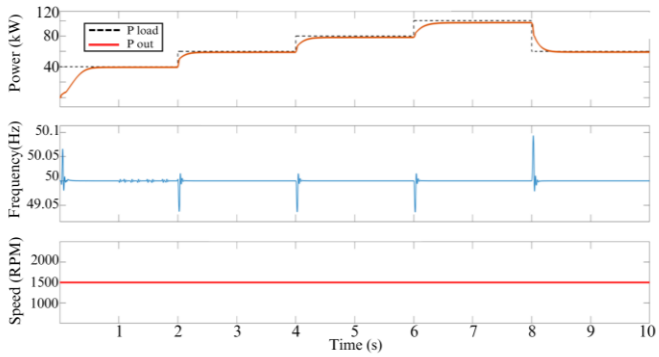

Fig. 10. Simulation result of BLDC diesel generator fixed speed 1500 RPM operation

D. *Load Modelling*

The load used is a resistive load connected in parallel. Each branch is equipped with a circuit breaker that will open at a predetermined time. This is to simulate load changes, as shown in figure 7.

III. Results and Discussion

The proposed system has been simulated using MATLAB/Simulink to illustrate performance of the system. Block diagram of the proposed system is shown in figure 8. Diesel engine provide torque (T_m) for generator to product electric power. Electric power must trough full-scale converter before arriving to load. In load, there is three phase measurement bus to calculate load demand for lookup table data in speed controller block.

A. *Diesel Engine Simulation Result*

The diesel engine that has been modeled previously is controlled using a fuzzy-Pi controller and is run in the variable speed mode following the load power demand value (P). The load changes every two seconds and then will be converted as a reference speed value by the lookup table. The controller regulates the diesel engine to reach the value of the reference speed as shown in Figure 9.

In the initial state, the system has an active power load of 40 kW and will increase by 20 kW every 2 seconds until second 8 and then decrease by 40 kW. The graph shows an

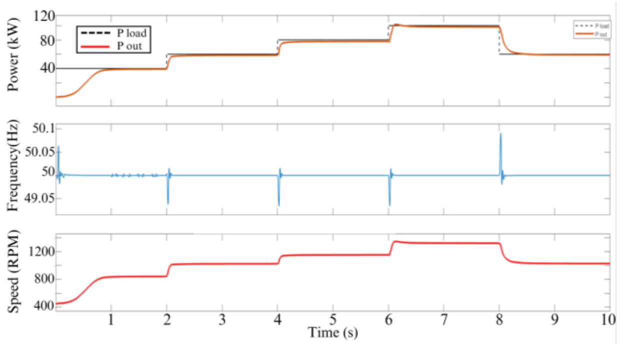

Fig. 14. Simulation result of BLDC diesel generator variable speed system

oscillation of about 0.2 seconds every time there is a change in the reference speed value before the system reaches stability. Oscillations occur most in the initial state when the control system tries to adapt. The control system improves over time as it adapts to reference changes. This is due to the advantages of fuzzy systems that have adaptive and intuitive properties in estimating values that are not previously patterned.

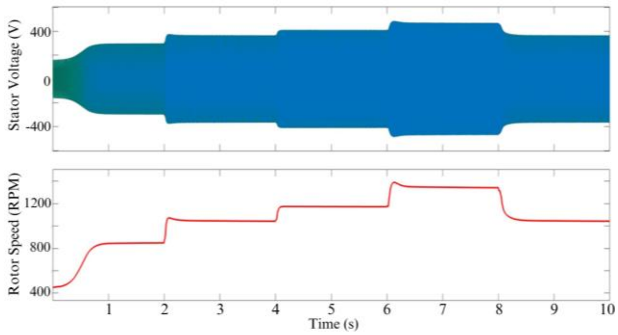

Fig. 11. Stator voltage behavior under speed changes

B. *BLDC Diesel Generator Simulation Result*

The amount of active power generated by the system when the BLDC generator is run at a fixed speed of 1500 RPM is shown in Figure 10. The active power generated changes with the load demand even though the generator is run at a constant speed. The resulting frequency is also stable at 50 Hz with a slight change of about 0.06 Hz during transient conditions. The full-scale converter system keeps the RMS voltage constant at 380 V so that the change in power is a result of the change in current.

Similar power results can also be obtained by running the generator in variable speed mode as shown in Figure 11. The active power transferred to the load corresponds to the load demand which changes every 2 seconds. This point can be achieved without any overshot value because The FLC in the power converter effectively stabilizes the input voltage for the inverter. Therefore, the inverter can provide AC power to the load just like a fixed speed generator does even though the generator is running in variable speed mode as shown in Figure 12.

C. *Power Converter Simulation Result*

The main problem in variable speed generators is that the frequency value of the voltage waveform and the resulting AC current will also change. So the role of the power converter is the main key to the stability of the system. The voltage conversion process performed by the full-scale converter on the system is shown in Figure 13.

Figure 13 shows the process of changing the voltage shape from the BLDC generator to the load. When operating at 1500 RPM, the generator produces a trapezoidal voltage with a peak value of 512 V (fig. 13.a). This shape is very favorable to be converted into DC voltage as shown in Figure 13.b when compared to sinusoidal waves. After

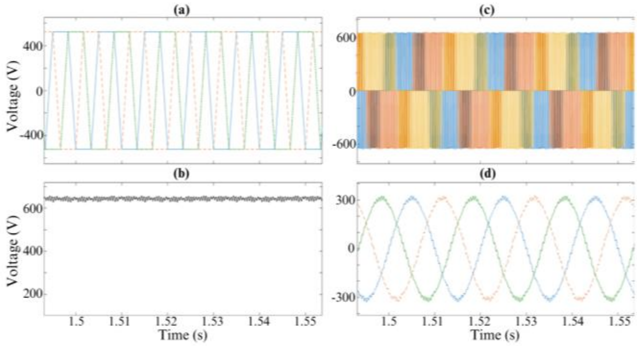

Fig. 12. Voltage conversion process, (a) stator (b) DC link (c) inverter (d) after L-C filter

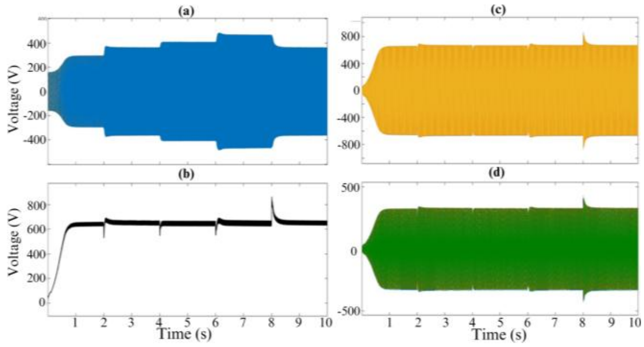

Fig. 13. Voltage simulation result for variable speed mode, (a) stator (b) DC link, (c) inverter, (d) after L-C filter

passing through a three full bridge rectifier, a DC voltage of 1024 V is obtained or twice the peak voltage of the generator.

Figure 13.b is the DC voltage resulting from the conversion of the buck-boost converter with FLC. This converter maintains the DC output voltage at 650 V with a ripple of about 30 V or 0.05%. The determination of the switching frequency, inductor, and capacitor values determines the magnitude of the ripple. Increasing the switching frequency is an effective method for minimizing voltage ripple.

The 3-phase multi-level inverter utilizes the DC input generated by the buck-boost converter to generate AC voltage pulses as shown in Figure 13.c. The inverter generates voltage pulses with the same peak value as the DC voltage value of 650 V with a ripple of 30 V just like in the DC link. The magnitude of this ripple depends on the DC voltage ripple. The less ripple in the DC voltage, the smaller the ripple generated by the inverter.

Figure 13.d is the AC voltage waveform from the inverter after passing through the L-C filter. The voltage has a peak line to ground value of 311 V or 380 Vrms line-to-line. There is a slight ripple in the sine waveform generated in this process which means it will increase harmonic distortion. Increasing the C value of the filter capacitor can reduce these

harmonics. But increasing the capacitor can also increase the reactive power in the system. So, determining the L-C value of the filter is particularly important.

The simulation results of the voltage value when the BLDC generator is run in variable speed mode are shown in Figure 14. During the 10-second simulation, the buck-boost converter with FLC succeeded in keeping the DC voltage within 650 V (fig. 14.B) under the changing stator voltage (fig. 14.A). Therefore, the AC voltage reaching the load can remain stable at 311 V or within 380 V RMS as if the generator was run in constant speed.

The stability of the DC link voltage is significantly influenced by the FLC design. The magnification of the error value and defuzzification value will accelerate the converter to reach the reference voltage value. But it will increase the possibility of overshot and oscillation. While increasing the delta error value will make the converter produce a more constant voltage value but will make the system more sensitive to noise. In this simulation, it is chosen to increase the delta error ten times and decrease the defuzzification value 0.02 times. It can be seen in the figure that the converter can reach the reference voltage value after 0.6 seconds without overshot.

Every time there is an increase in load, which in the simulation occurs every 2 seconds, there is a momentary decrease in the voltage. There is a decrease of about 60 V when the active load increases by 20 kW. The drop has an impact on the load voltage drop but has no impact at all on the generator, so the generator remains safe. The FLC takes 0.15 seconds before it can restore voltage stability again.

D. *Diesel Engine Fuel Efficiency*

Fuel efficiency comparation between fixed speed operation and variable speed operation can be obtained from simulation result and based on fuel efficiency map (fig. 1) as follows:

TABLE VII. FUEL EFFICIENCY COMPARATION

Output Power (kW)	Fuel Efficiency (kg/kWh)	
	Fixed speed	Variable speed
40	0.238	0.220
60	0.227	0.216
80	0.223	0.219
100	0.204	0.204

variable speeds operation is proven to reduce fuel consumption. the lower the power that needs to be generated the higher the reduction in fuel consumption. so that variable speeds operation is more suitable for small to medium generators.

Fuel consumption is commonly measured in liters rather tan kilograms. Density of petroleum diesel fuel is 0.84 kg/l, so the fuel consumption in liter per hour for each power output can be calculated using equation 5.

$$\text{Fuel consumption} = \frac{\text{speed efficiency}}{\text{fuel density}} \times \text{power output} \tag{5}$$

Increased fuel consumption efficiency for each load can be obtained from the following simple calculation.

- 40 kW load

  Fuel consumption in fixed speed: $\frac{0.238\times40}{0.84} = 11.33$ L/h

  Fuel consumption in variable speed: $\frac{0.22\times40}{0.84} = 10.47$ L/h

  Increasing fuel efficiency: $\frac{11.33\text{-}10{,}47}{11.33}\times100\% = 7.6\%$
- 60 kW load

  Fuel consumption in fixed speed: $\frac{0.227\times60}{0.84} = 16.21$ L/h

  Fuel consumption in variable speed: $\frac{0.216\times60}{0.84} =15.42$ L/h

  Increasing fuel efficiency: $\frac{16.21-15.42}{16.21}\times100\% = 4.8\%$
- 80 kW load

  Fuel consumption in fixed speed: $\frac{0.223\times80}{0.84} = 21.23$ L/h

  Fuel consumption in variable speed: $\frac{0.218\times80}{0.84} = 20.76$ L/h

  Increasing fuel efficiency: $\frac{21.23\text{-}20{,}76}{21.23}\times100\% = 2.3\%$
- 100 kW load

  Fuel consumption in fixed speed: $\frac{0.204 \times 100}{0.84} = 24.28$ L/h

  Fuel consumption in variable speed: $\frac{0.204 \times 100}{0.84} = 24.28$ L/h

  Increasing fuel efficiency: $\frac{24.28-24.28}{24.28}\times100\% = 0\%$

IV. CONCLUSION

This study demonstrates that a variable-speed diesel generator system using a BLDC generator and a fuzzy logic-based controller (FLC) can effectively reduce fuel consumption by up to 7.6% (0.86 liters/hour for a 100 kW generator) while maintaining voltage and frequency stability (380 Vrms and 50 Hz). The FLC's adaptive nature allows it to handle load variations and nonlinearities without requiring precise system modeling, enhancing reliability in dynamic and remote applications. Additionally, the system's improved fuel efficiency contributes to lower greenhouse gas emissions, supporting environmental sustainability and compliance with stricter regulations. Its robust voltage and frequency stabilization also make it compatible with hybrid systems, enabling integration with renewable energy sources. Future research should validate real-world performance and explore advanced FLC designs for greater efficiency and adaptability.

ACKNOWLEDGMENT

The support for this research was provided by Institut Teknologi Sepuluh Nopember (ITS) Surabaya, which the authors recognize.

REFERENCE

[1] Laboratoire de Recherche en Énergie Éolienne, Université du Québec à Rimouski, 300 allée des ursulines, Rimouski, Québec G5L 3A1, Canada *et al.*, "Variable Speed Diesel Electric Generators: Technologies, Benefits, Limitations, Impact on Greenhouse Gases Emissions and Fuel Efficiency," *JEPT*, vol. 4, no. 1, pp. 1–1, Jul. 2021, doi: 10.21926/jept.2201003.

[2] M. Mobarra, B. Tremblay, M. Rezkallah, and A. Ilinca, "Advanced Control of a Compensator Motor Driving a Variable Speed Diesel Generator with Rotating Stator," *Energies*, vol. 13, no. 9, p. 2224, May 2020, doi: 10.3390/en13092224.

[3] D. H. Wang, C. V. Nayar, and C. Wang, "Modeling of stand-alone variable speed diesel generator using doubly-fed induction generator," in *The 2nd International Symposium on Power Electronics for Distributed Generation Systems*, Hefei, China: IEEE, Jun. 2010, pp. 1–6. doi: 10.1109/PEDG.2010.5545769.

[4] T. Waris and C. V. Nayar, "Variable speed constant frequency diesel power conversion system using doubly fed induction generator (DFIG)," in *2008 IEEE Power Electronics Specialists Conference*, Rhodes, Greece: IEEE, Jun. 2008, pp. 2728–2734. doi: 10.1109/PESC.2008.4592357.

[5] M. Z. Z. Muhtadi, H. Suryoatmojo, and M. Ashari, "Improving fuel consumption efficiency of synchronous diesel generator operated at adjustable speed using adaptive inertia weight particle swarm optimization algorithm," vol. 8, no. 4, 2023.

[6] H. Suryoatmojo, A. R. Aulia, D. C. Riawan, R. D. Dzulfikar, Prabowo, and Suwito, "Optimal Control of Diesel Engine Generator Using Variable Speed Permanent Magnet Synchronous Generator Based on Fuzzy Controller," in *2022 10th International Conference on Smart Grid and Clean Energy Technologies (ICSGCE)*, Kuala Lumpur, Malaysia: IEEE, Oct. 2022, pp. 65–71. doi: 10.1109/ICSGCE55997.2022.9953645.

[7] M. Rezkallah *et al.*, "Coordinated Control Strategy for Hybrid off-Grid System Based on Variable Speed Diesel Generator," *IEEE Trans. on Ind. Applicat.*, vol. 58, no. 4, pp. 4411–4423, Jul. 2022, doi: 10.1109/TIA.2022.3174825.

[8] H. Suryoatmojo, Y. Azmi, Prabowo, and Soedibyo, "Optimal Control of Diesel Engine Generator Using Variable Speed Doubly Fed Induction Generator to Reduce Fuel Consumption," 2023, *ICIC International 学会*: 03. doi: 10.24507/ijicic.19.03.789.

[9] G. Iwanski, Ł. Bigorajski, and W. Koczara, "Speed control with incremental algorithm of minimum fuel consumption tracking for variable speed diesel generator," *Energy Conversion and Management*, vol. 161, pp. 182–192, Apr. 2018, doi: 10.1016/j.enconman.2018.01.053.

[10] Fang Lin Luo and Hock Guan Yeo, "Advanced PM brushless DC motor control and system for electric vehicles," in *Conference Record of the 2000 IEEE Industry Applications Conference. Thirty-Fifth IAS Annual Meeting and World Conference on Industrial Applications of Electrical Energy (Cat. No.00CH37129)*, Rome, Italy: IEEE, 2000, pp. 1336–1343. doi: 10.1109/IAS.2000.882057.

[11] D. B. Minh, V. D. Quoc, and P. N. Huy, "Efficiency Improvement of Permanent Magnet BLDC Motors for Electric Vehicles," *Eng. Technol. Appl. Sci. Res.*, vol. 11, no. 5, pp. 7615–7618, Oct. 2021, doi: 10.48084/etasr.4367.

[12] P. M. De Almeida, R. L. Valle, P. G. Barbosa, V. F. Montagner, V. Cuk, and P. F. Ribeiro, "Robust Control of a Variable-Speed BLDC Motor Drive," *IEEE J. Emerg. Sel. Top. Ind. Electron.*, vol. 2, no. 1, pp. 32–41, Jan. 2021, doi: 10.1109/JESTIE.2020.3035055.

[13] J. E *et al.*, "Experimental investigation on performance and economy characteristics of a diesel engine with variable nozzle turbocharger and its application in urban bus," *Energy Conversion and Management*, vol. 193, pp. 149–161, Aug. 2019, doi: 10.1016/j.enconman.2019.04.062.

[14] H.-W. Lee, T.-H. Kim, and M. Ehsani, "Practical Control for Improving Power Density and Efficiency of the BLDC Generator," *IEEE Trans. Power Electron.*, vol. 20, no. 1, pp. 192–199, Jan. 2005, doi: 10.1109/TPEL.2004.839805.

[15] X. Weng *et al.*, "Comprehensive comparison and analysis of non-inverting buck boost and conventional buck boost converters," *J. eng.*, vol. 2019, no. 16, pp. 3030–3034, Mar. 2019, doi: 10.1049/joe.2018.8373.