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Optimal power dispatch in a multisource system using fuzzy logic control

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Abstract

The rising of hybrid system controllers, in real-time renewable energy for the optimum energy management system (EMS), required the design of a real-time controller to operate the entire system in real time. The increasing popularity of Renewable Energy (RE) has a control strategy, that determined the overall efficiency of the hybrid system (HS), although the energy management system of these systems is particularly complex to be managed. The paper's main contribution is to investigate the feasible controller and, later, to present an advanced control strategy for managing and controlling the flow of hybrid renewable energy (HRE) with a diesel generator (DG) and battery (BT) as a backup in rural application of South Africa (SA) . EMS was implemented using a fuzzy logic controller (FLC) in MATLAB/SIMULINK. This study analysed input and output variables for the design of a controller, with a set of rules and a three-dimension (3D) surface. Simulated results are similar studies conducted between previous years and now, however, they differ in their objectives. A Fuzzy Logic Controller (FLC) was considered as the most suitable option to be used to control the entire system and further demonstrated acceptable performance in managing the power flow between the sources under various loads demands, while at the same time storing excess energy in the battery. This study finally answers the question of the feasibility of the controller in real-time applications. However, further investigation is to be conducted, to establish further results in real time, through the programmed FLC for smooth performance in hardware-in-the-Loop (HIL) test equipment.

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Keywords: Fuzzy logic controller; Renewable energy system; Power flow; Energy management system

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1. Introduction

The hybrid renewable energy system (HRES), is gaining popularity in remote rural areas to be electrified globally, to generate low-carbon emissions [1,2] by moving away from the traditional energy network. RE has recently been used in various countries for isolated homes aimed at controlling the flow of HRES power, in particular, the

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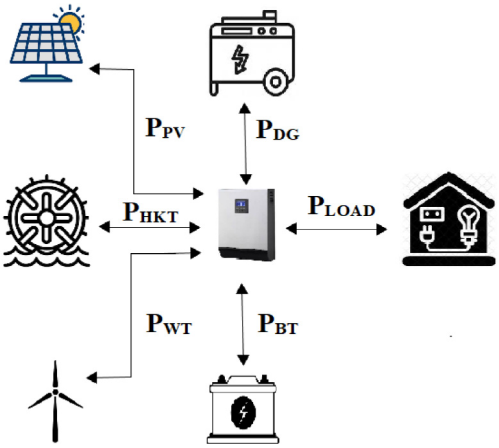


Fig. 1. Schematic diagram of PV/PHK/WT/DG/BT power system with FLC.

combination of solar and wind power [3]. The combination of RE and storage is increasingly offering an optimal solution to the problem caused, or created, by conventional power [3]. The involvement of more than one type of RE sources plays a crucial role and proper storage may increase the reliability and efficiency of the HRES to a greater extent [4]. It has been pointed out [5] that it is important to include storage devices in remote locations, due to the fluctuating nature of the RES generated power. Energy management (EM), was performed by [6], before using three different controllers, such as FLC [7,8], neural network [9] and genetic algorithm [10] in the HRES. FLC was considered amongst the recent developments in control techniques and advanced control strategy required, to ensure load balancing [11,12]. The implementation of FLC is used to manage the flow of energy in the extended hybrid renewable system [4] which has been investigated, in order to satisfy the load of the isolated system or mode in other parts of the world. EMS was further used, to optimally share power between the different components within the RE [13]. A number of techniques have previously been used to manage the flow of energy in the hybrid system, in particular, photovoltaic (PV)/WT, however, a system with more than three components has not been implemented to manage and control the flow of power. Previous work has shown that FLC may manage complex systems, such as HES [14–17]. The paper's main contribution, is to investigate the feasible controller and, later, to present an advanced control strategy for managing and controlling the flow of hybrid renewable energy with diesel generator (DG) and battery (BT), as a backup in rural South African (SA) applications. The paper is organized as follows: the following section briefly explains the configuration of the proposed system; Section 3 presents the details of the fuzzy logic strategy for energy management; Section 4 sets out the results of the simulation and discussion. The last section outlines the conclusion of this study.

2. System configuration

Fig. 1, illustrates a schematic diagram of the PV/PHK/WT hybrid microgrid power system, with BT and DG as a backup. This involves an energy management controller that sends/receives signals to or from any of the renewable energy systems (RES) and back-up systems. Notifying the sources on, when to be ON/OFF, in order to produce the energy required to meet the load demand. A block diagram of FLC, shown in Fig. 2, is used to manage and control the energy required by the load. FLC maintains the power flow of the system balanced during the short fall of power, when the backup needs to start or when the battery needs to be charged and discharged for the purpose of well managed electrification through the applied rules.

The power management strategy of PV/PHK/WT, with backup for a microgrid power system, is implemented as shown in Fig. 1. The power flow is based on FLC, to balance the power through the expressed equation (1) below:

$$P_{PV} + P_{PHK} + P_{WT} + P_{DG} + P_{BT} = P_L \tag{1}$$

P_{PV} denotes power extracted from PV to the load and is stored in the battery; $P_{PHK} + P_{WT}$ denotes power generated from the Pico hydrokinetic and wind turbine throughout the day at the same time stored; P_{DG} denotes power from

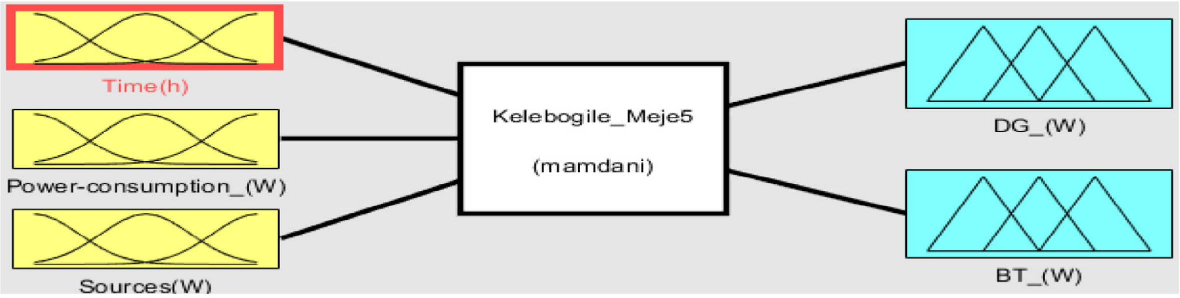


Fig. 2. Block diagram of FLC energy management electrical system.

Table 1. FLC rules for input and output variables.

Input 1(Time in h.)	Input 2(Power consumption in W)	Input 3 (RES in W)	Output (Backup in W)
MOP (00:00–4:00)	VLC (0–400)	PHK	BT
MP (03:30–6:00)	LC (350–600)	WT	BT
MD (05:30–16:00)	MC (450–660)	PHK+PV	BT
APD (15:30–17:00)	AC (550–780)	PV	BT
EP (16:30–22:00)	HC (750–1080)	WT	DG
EOP (21:30–23:00)	VHC (1050–1140)	PHK	DG

Table 2. Specifications and parameters for PV/PHK/WT and backup hybrid system.

Components description	Parameter	Value
PV	SunPower SPR-415-WHT-D	15-module string 15 parallel strings
PHK	Synchronous machine with hydraulic turbine and governor	–
WT	Generator	480/275 kVA
DG	Synchronous machine with diesel governor and excitation machine	–
BT	Generic	40 Ah, 48 VDC

diesel generator; P_{BT} denotes power from the battery (may also be negative); P_L is the power demand from AC load.

3. Fuzzy logic energy management control

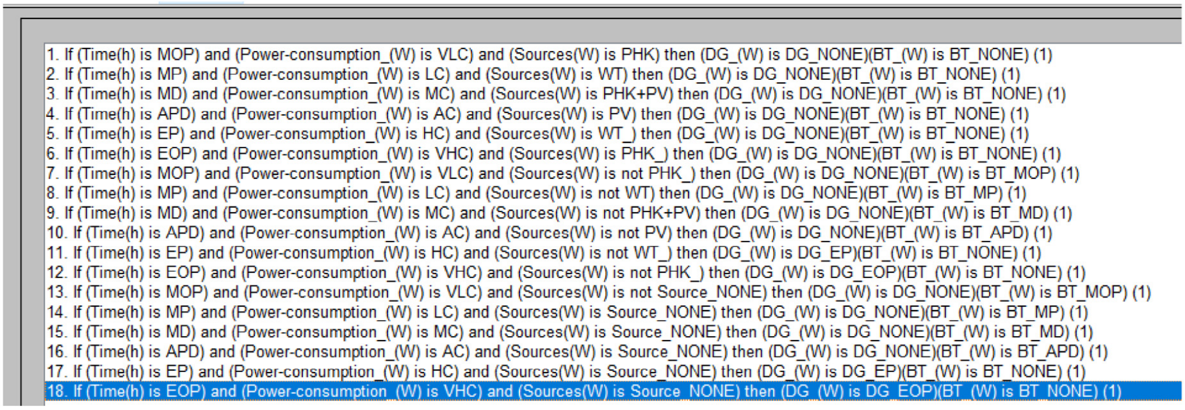
The fuzzy logic-based energy management control technique, is described in detail in this section. The average maximum load demand for 6 households is assumed to be 1.14 kW. With regards to the design of a fuzzy logic controller for the proposed rural microgrid system, the controller should be used for energy management, by sending signals to all hybrid system components at a specified time.

3.1. Input and output of fuzzy controller

The configuration of the fuzzy logic controller includes the input and output variables indicated in Table 1. Load consumption (kW), renewable energy sources (kW) and time(hrs) are selected input variables, with a diesel generator (kW) and battery (kW), as output variables. FLCs have the potential to work with data that is incorrect and that does not require an accurate mathematical model [12]. At a very low, average or medium consumption, the renewable energy system (RES) is expected to be able to meet the load demand, without a backup over a specific period as shown in Table 1. The backup system may solely work in unforeseeable circumstances, if either of the RES cannot function (see Table 2).

3.2. Fuzzy logic rules and surface

Approximately 18 sets of IF–THEN rules governing input and output variables from the fuzzy rule editor in MATLAB, when preparing the modelling of the designed hybrid controller in Simulink. The rules may be adjusted



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1. If (Time(h) is MOP) and (Power-consumption_(W) is VLC) and (Sources(W) is PHK) then (DG_(W) is DG_NONE)(BT_(W) is BT_NONE) (1)
2. If (Time(h) is MP) and (Power-consumption_(W) is LC) and (Sources(W) is WT) then (DG_(W) is DG_NONE)(BT_(W) is BT_NONE) (1)
3. If (Time(h) is MD) and (Power-consumption_(W) is MC) and (Sources(W) is PHK+PV) then (DG_(W) is DG_NONE)(BT_(W) is BT_NONE) (1)
4. If (Time(h) is APD) and (Power-consumption_(W) is AC) and (Sources(W) is PV) then (DG_(W) is DG_NONE)(BT_(W) is BT_NONE) (1)
5. If (Time(h) is EP) and (Power-consumption_(W) is HC) and (Sources(W) is WT_) then (DG_(W) is DG_NONE)(BT_(W) is BT_NONE) (1)
6. If (Time(h) is EOP) and (Power-consumption_(W) is VHC) and (Sources(W) is PHK_) then (DG_(W) is DG_NONE)(BT_(W) is BT_NONE) (1)
7. If (Time(h) is MOP) and (Power-consumption_(W) is VLC) and (Sources(W) is not PHK_) then (DG_(W) is DG_NONE)(BT_(W) is BT_MOP) (1)
8. If (Time(h) is MP) and (Power-consumption_(W) is LC) and (Sources(W) is not WT) then (DG_(W) is DG_NONE)(BT_(W) is BT_MP) (1)
9. If (Time(h) is MD) and (Power-consumption_(W) is MC) and (Sources(W) is not PHK+PV) then (DG_(W) is DG_NONE)(BT_(W) is BT_MD) (1)
10. If (Time(h) is APD) and (Power-consumption_(W) is AC) and (Sources(W) is not PV) then (DG_(W) is DG_NONE)(BT_(W) is BT_APD) (1)
11. If (Time(h) is EP) and (Power-consumption_(W) is HC) and (Sources(W) is not WT_) then (DG_(W) is DG_EP)(BT_(W) is BT_NONE) (1)
12. If (Time(h) is EOP) and (Power-consumption_(W) is VHC) and (Sources(W) is not PHK_) then (DG_(W) is DG_EOP)(BT_(W) is BT_NONE) (1)
13. If (Time(h) is MOP) and (Power-consumption_(W) is VLC) and (Sources(W) is not Source_NONE) then (DG_(W) is DG_NONE)(BT_(W) is BT_MOP) (1)
14. If (Time(h) is MP) and (Power-consumption_(W) is LC) and (Sources(W) is Source_NONE) then (DG_(W) is DG_NONE)(BT_(W) is BT_MP) (1)
15. If (Time(h) is MD) and (Power-consumption_(W) is MC) and (Sources(W) is Source_NONE) then (DG_(W) is DG_NONE)(BT_(W) is BT_MD) (1)
16. If (Time(h) is APD) and (Power-consumption_(W) is AC) and (Sources(W) is Source_NONE) then (DG_(W) is DG_NONE)(BT_(W) is BT_APD) (1)
17. If (Time(h) is EP) and (Power-consumption_(W) is HC) and (Sources(W) is Source_NONE) then (DG_(W) is DG_EP)(BT_(W) is BT_NONE) (1)
18. If (Time(h) is EOP) and (Power-consumption_(W) is VHC) and (Sources(W) is Source_NONE) then (DG_(W) is DG_EOP)(BT_(W) is BT_NONE) (1)
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Fig. 3. (h)FLC rules for input and output variables.

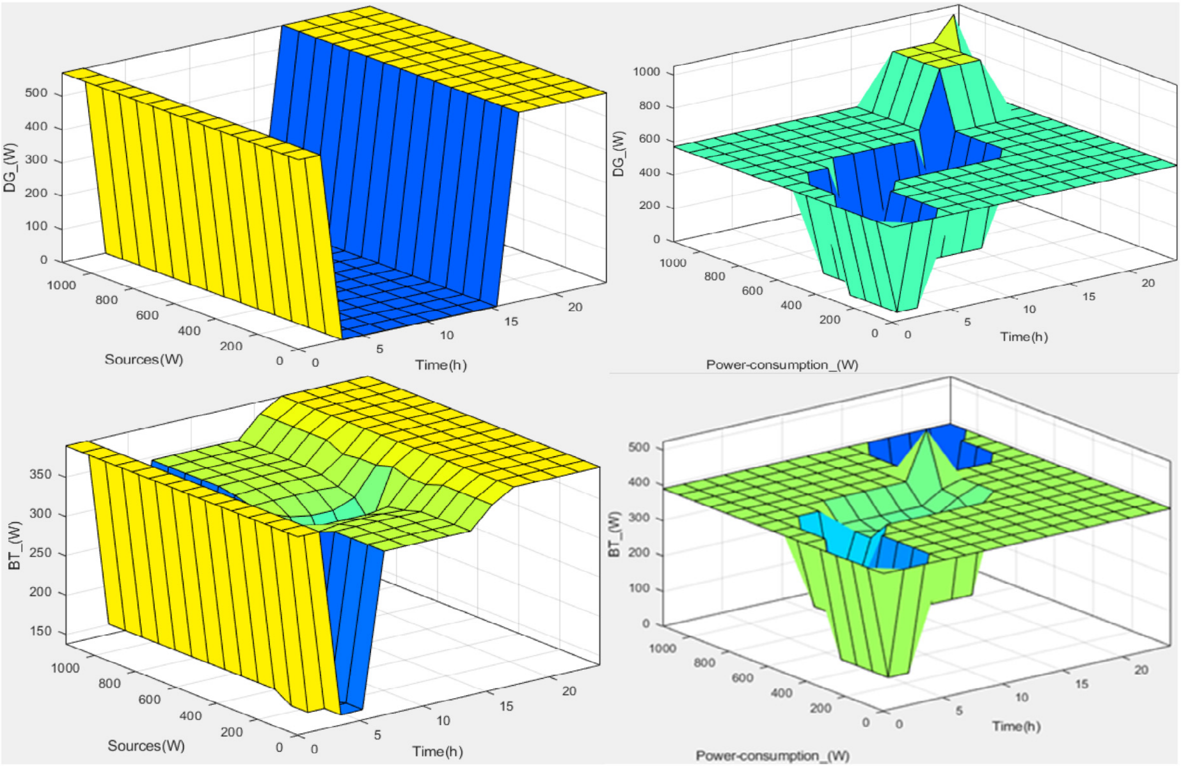

Fig. 4. FLC surface function with BT and DG output.

and easily viewed for the expected results. The rules set for input and output variables in Fig. 3 depicts a 3D fuzzy surface in MATLAB. Fig. 4 basically depicts the output surfaces of the system against three inputs of the system and, upon opening the surface viewer, Fig. 4 further presented a three-dimensional curve that represents the mapping of time (h) power consumption (W), to backup systems (W).

The input and output variables in Fig. 5, depicts details influenced by the membership functions, in order to view the entire surface of the fuzzy inference system, as to how the system operates in Simulink and plots every part of every rule.

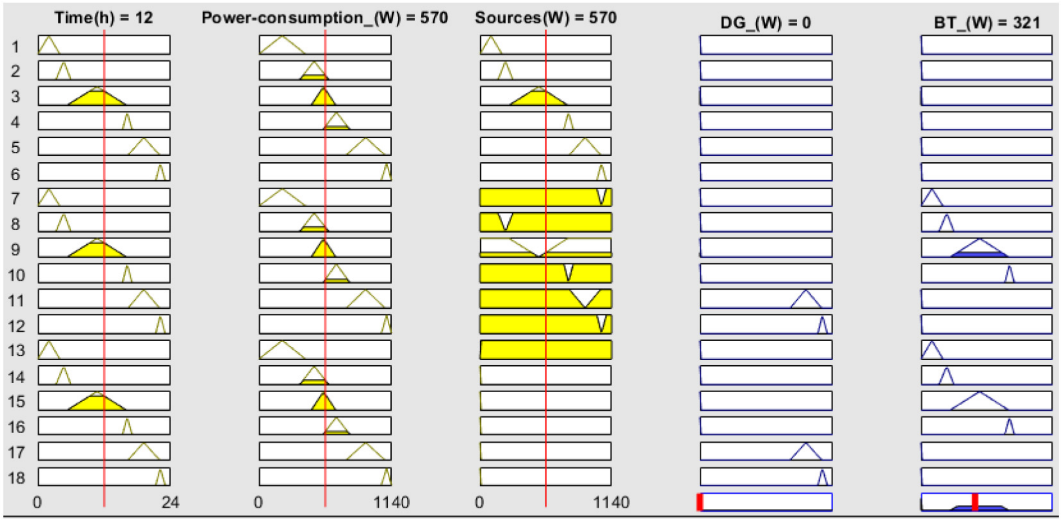

Fig. 5. FLC input and output results set.

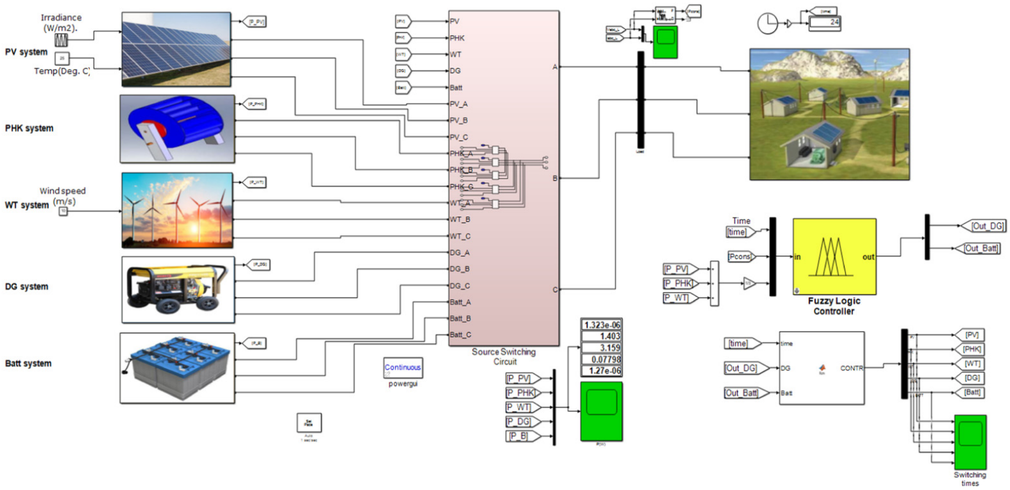

Fig. 6. Simulink model of overall PV/PHK/WT with backup power system.

4. Results and discussion

The overall power of PV/PHK/WT model in MATLAB/SIMULINK, with a backup system and FLC, is displayed in Fig. 6. In order to avoid power flow imbalance based on load demand, an FLC was used to send a signal to each component, as required by load. If adequate power is lost to provide load, the backup device receives a signal to provide the load demand from FLC. In Fig. 8, energy begins to be used by end users at the early hours of the day and in the afternoon, however, it remains steady at other times of the day.

WT and PHK have the ability to operate throughout the day and PV during the day only. FLC is programmed to send a signal to each RE at a specific time, for load balancing or maintaining stable power output, in order to avoid the use of BT and DG timeously, unless there is an emergency or when the system fails to meet the load. IF and THEN FLC rule sends a signal to PHK at VLC, to operate between 00:00 to 04:00 AM. Thereafter, WT receives a signal to take over between 03:30 to 06:00 AM, to start operating at LC. Between 05:30 and 16:00 PM at MC, the controller again sends signal to the combination of PHK and PV, however PHK begins to operate from 05:30 to 7:30 AM and PV takes over until 17:00 PM at AC. Between 16:30 and 22:00 PM, where there is HC, WT resumes operating. PHK takes over from WT between 21:30 to 23:00 PM, after receiving signal from FLC at

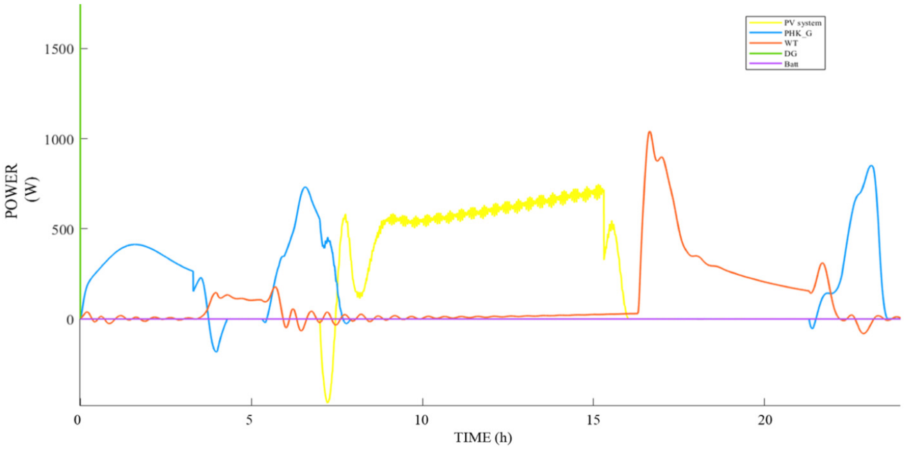

Fig. 7. Output power produced by RES during FLC mode without backup.

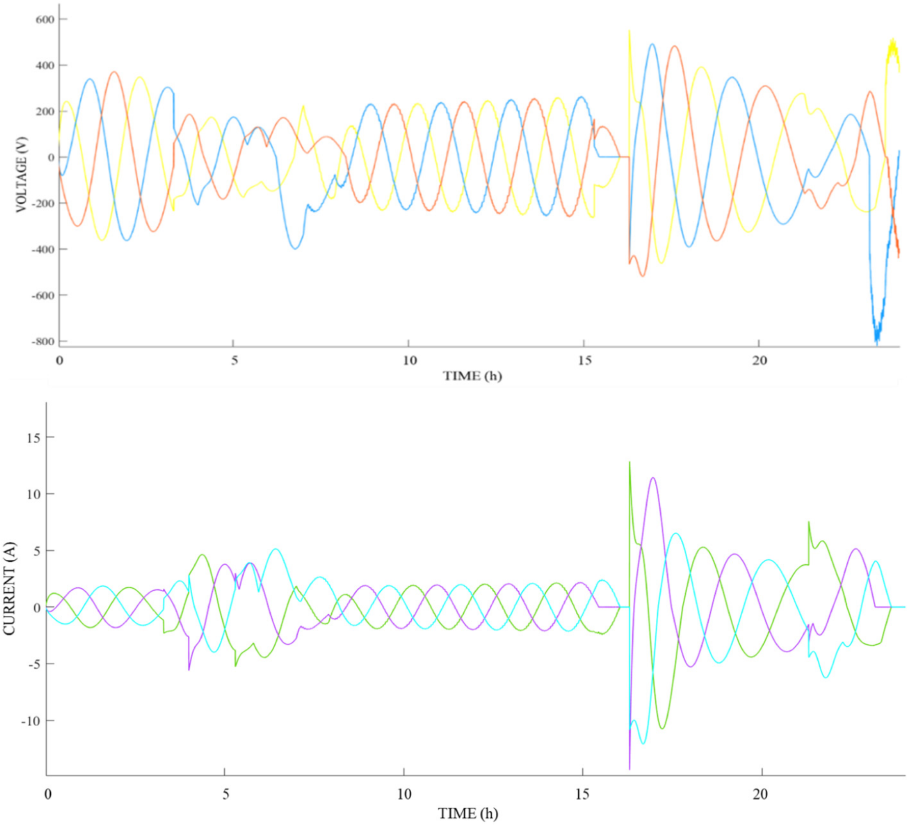

Fig. 8. Voltage and Current waveforms during the fuzzy model.

VHC. The battery is charged as each component starts operating and is discharged whenever there are shortfalls or emergencies in the HRES operation, as shown in Fig. 7.

5. Conclusion

The FLC was developed to successfully operate the power system control, due to the difficulty of load fluctuation. A PV/PHK/WT hybrid system with a backup system based FLC, was introduced for this study. The findings of the simulation showed that FLC-based management strategy does not only provide the load, it further assists in keeping batteries charged, without allowing DG to operate fully, but only when the system experiences unpredictable power failure. Moreover, the power system has improved the operating performance, though further ideas are to be involved, to create smooth and optimal performance.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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