Hybrid Power Supply System with Fuzzy Logic Controller: Power Control Algorithm, Main Properties, and Applications

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***Abstract*—This paper presents a novel power supply system based on the use of fuzzy inference logic to improve the power control of renewable energy sources. The system comprises renewable solar and wind sources, and an accumulator battery is used as an additional power source. The procedure for the parallel connection of multiple energy sources provides a stable power supply and optimal charging of the accumulative element. Renewable energy sources are connected in parallel using two serial converters and controlled by the controller based on the fuzzy logic. The reference voltage control of the serial converter enables an optimal use of available energy sources. The accumulative element is connected in parallel to compensate for the shortage of solar and wind energies, whereas if the available renewable energy exceeds the needs of the consumers, the surplus energy is accumulated in the battery. All measurements are conducted on the prototype of the hybrid power system under real conditions and compared with the applied systems of this type. This novel system is mainly used in remote telecom locations where there is no power distribution network.**

***Index Terms*—Fuzzy logic, hybrid power source, power supply, parallel operation, serial converter.**

I. Introduction

THE power supply sources are vital for the telecommunication and information systems. Regardless of the problems related to voltage variations, over-voltage, under-voltage, interruptions in the operation of power sources, thunder strikes, and meteorological turbulences, the power sources need to work reliably. European Union Agency for Network and Information Security (ENISA) annual incident report 2017 [1]-[4] shows that a significant number of power outages, leading to a serious disturbance of services, will not lead to severe consequences if the protection measures function properly. The report also states that power outages are identified as among the first five causes of incidents and service termination in different systems.

To increase the reliability of the power supply, a principle of the parallel operation of renewable energy sources has been introduced, which includes three forms.

1) Parallel operation of different energy sources. Consumers are powered by two or more power supplies that use different energy sources.

2) Parallel operation of multiple modules powered by a single power source. Consumers are powered by one power source through a device that has multiple modules during parallel operation.

3) Parallel operation of multiple power sources by modular power supplies. Consumers are powered by two or more power sources through a device that has multiple modules during parallel operation.

Recent researches and developments in the field of renewable energy sources show the potential of renewable energy sources as a form of supplemental energy for conventional energy production systems [5]-[8]. In this study, a reliable novel solution is presented for the hybrid power supply of the telecommunication and information equipment, using solar, wind, and secondary battery energy sources controlled by a fuzzy logic controller.

The remainder of this paper is as follows. Section II describes a hybrid power supply system that adopts two different renewable energy sources and an accumulative element. Section III describes the concept of a hybrid power supply system especially the control algorithm based on the fuzzy logic. In the proposed solution, the energy source only provides as much energy as the consumer needs. The practical realization of the novel hybrid power supply system for a single telecommunication center and the results obtained are presented in Section IV. The discussion and conclusion are given in Sections V and VI, respectively.

II. Hybrid Power Supply System

Power systems that use different energy sources and allocate power, according to the adaptive algorithm, are called programmable hybrid power supply systems (PHPSSs). Such

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hybrid systems include more than one energy source [9], [10] and can range from a simple network for individual consumers to a widespread network for a group of consumers. Renewable energy sources such as solar energy, wind energy, or small hydropower plants provide a realistic alternative to the power supply in remote areas where there is no power distribution network or the power distribution network is unreliable [11], [12]. There are many solutions for hybrid power sources based on photovoltaic (PV), wind generators (WGs), batteries, and controllers for energy management [13]-[15]. The applications of hybrid power sources are extremely different from wireless communications to residential applications [16]-[18]. There are various solutions with energy controllers of hybrid power system based on neural networks and the fuzzy logic, solutions with three-level controllers, and hybrid power flow controllers [19]-[21]. PV cells can be combined with fuel cells (FCs), supercapacitors, or secondary batteries [22]-[24]. The stand-alone or autonomous hybrid power systems with three or four different sources such as WG/PV/FC/battery and WG/PV/FC/ultra-capacitor have been investigated during the last decade [25], [26]. This brief description proves that the hybrid power source field has many possibilities for the further research and applications.

Figure 1 shows the block diagram of a hybrid power supply system that uses solar and wind energies as well as the energy derived from the generator or power distribution network through P1. The proposed solution has the minimum number of voltage conversions. The battery is used to maintain the stability of the system and to accumulate surplus electricity. The accumulated energy is used when there is insufficient energy available to consumers.

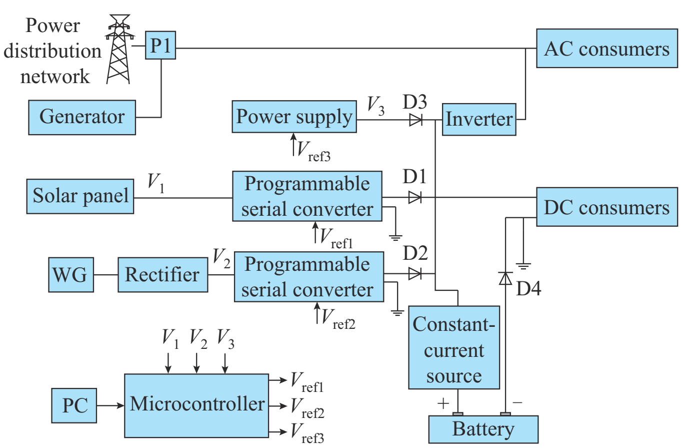

Fig. 1. Block diagram of hybrid power supply system and fuzzy logic controller.

The principle of electricity generation from the hybrid power supply system is a comprehensive process [8] that allows the maximum utilization of each available energy source. In this system, it is necessary to connect various renewable energy sources (e.g., solar and wind energies) with batteries.

In Fig. 1, V_1, V_2, and V_3 are the voltage of WG, the voltage of solar panel, and the output voltage from power supply, respectively; and V_{ref1}, V_{ref2}, and V_{ref3} are the serial stabilizer to which the WG is connected, the serial stabilizer to which the solar panel is connected, and the reference values of the power supply, respectively. The diodes D1, D2, D3, and D4 enable the DC currents from renewable energy sources and the protection of current-voltage feedback and short circuits. The electricity produced is forwarded to the consumer and battery. The consumer uses the energy necessary for a proper operation. The surplus energy obtained from the available sources is forwarded to the battery. The battery is charged from a constant-current source according to the specified charging algorithm prescribed by the manufacturer. The installation of hybrid power supply systems in remote areas should provide a reliable electricity supply. The distribution of power from remote sources powered on fossil fuels is expensive, and costs drastically increase with the distance from the site.

Optimally, a distributed power supply is used, which provides the parallel operation of renewable energy sources and energy sources based on fossil fuels [27]. For the power supply used in telecommunication centers, where the power distribution network is unavailable, it is possible to use the following energy sources: WG, solar panel, generator, accumulative element (battery).

III. Control Algorithm of Hybrid Power Supply System

Hybrid power supply systems often aim to maximize the use of renewable energy sources. The purpose of the proposed hybrid system is to provide the necessary energy to consumers and optimal charging of the accumulator batteries. Figure 2 shows a block diagram of the two renewable energy sources and a rechargeable battery connection. This configuration is for power consumers using DC voltage.

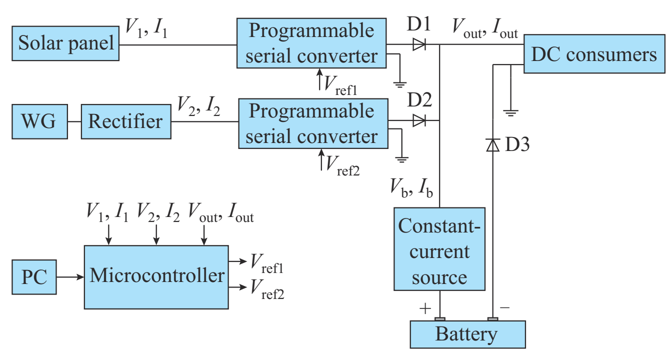

Fig. 2. Block diagram of measurement configuration.

The output power of renewable energy sources essentially depends on the non-electrical parameters, which are the primary energy sources (solar and wind energies). Renewable energy sources cannot be directly connected to consumers (as shown in Figs. 1 and 2) but require programmable serial DC/DC converters to adjust the voltages for the battery charging and the needs of DC consumers. In Fig. 2, V_b and I_b are the voltage and current of the battery, respectively; and V_{out} and I_{out} are the output voltage and current for the DC consumers, respectively. If one source does not provide sufficient power to supply the consumers, the voltage at its output will decrease, which could lead to irregular consumer operation. To prevent the voltage drop during a consumer installation, a second energy source is added in parallel. Both energy sources are connected to the consumer using a programmable serial stabilizer. The output voltages of both DC/DC converters are adjusted by changing the reference voltage in the amplifier located in the control electronics of the converter. Figure 3 shows a schematic diagram of the method to adjust the output voltage for the consumer supply in the system with two different energy sources and the accumulator battery. The voltage and battery charging current should be in accordance with the specifications prescribed by the battery manufacturer. The function of the accumulative element is to accumulate surplus energy (if it exists) to ensure a stable power supply to the consumers during the period in which the renewable energy sources do not provide sufficient energy.

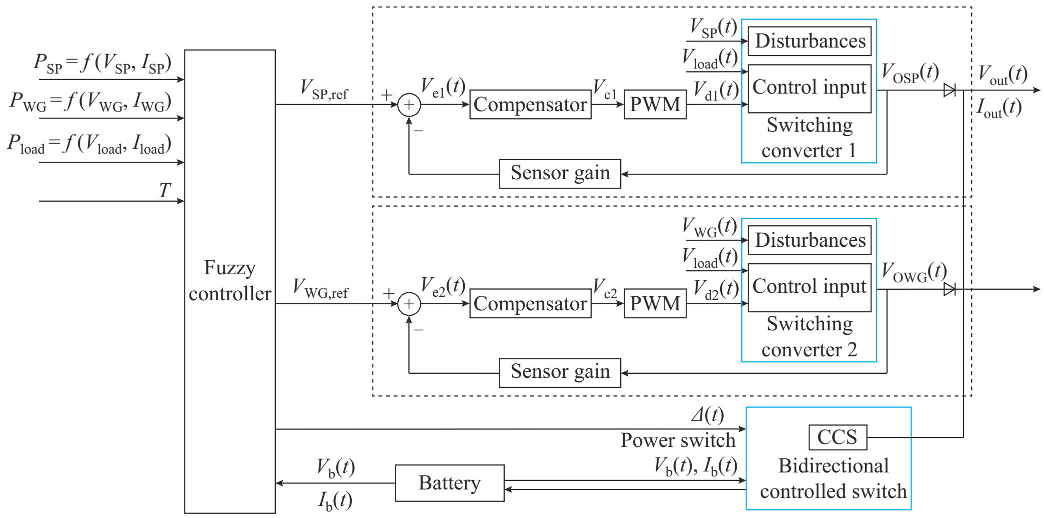

Fig. 3. Schematic diagram of method to adjust output voltage for consumer supply.

In Fig. 3, V_{SP}, I_{SP}, and P_{SP} are the voltage, current, and power of the solar panel, respectively; V_{WG}, I_{WG}, and P_{WG} are the voltage, current, and power of the WG, respectively; V_{load}, I_{load}, and P_{load} are the voltage, current, and power of conumers, respectively; $V_{SP,ref}$ and $V_{WG,ref}$ are the reference values of the serial stabilizer to which the solar panel is connected and the serial stabilizer to which the WG is connected, respectively, and V_{e1} and V_{e2} are their corresponding errors; V_{OSP} and V_{OWG} are the output voltages obtained from the serial stabilizer to which the solar panel is connected and the serial stabilizer to which the WG is connected, respectively; V_{c1} and V_{c2} are the values of the DC output at the amplifier output; V_{d1} and V_{d2} are the pulse width modulation (PWM) impulses; $\Delta(t)$ is the difference between the required and available power as a function of time; and T is the temperature.

By changing the reference value of the serial stabilizer, the output voltage of the serial stabilizer is maintained at the desired value. If the available power of the source is greater than the power required by consumers, the change of the δ factor maintains the output voltage, regardless of the change of the input voltage and load current (consumer power). If the consumer power is greater than the available power of one source, it is necessary to use the energy from another source. The reference voltage of another energy source is adjusted so that it operates in parallel with the first energy source, and a constant output voltage is obtained. The lack of the power of one energy source is compensated by the power of another energy source. The change of the δ factor of each serial stabilizer compensates for the change of the available energy from all sources.

The output voltage of the DC/DC converter depends on the input voltage and δ factor, as given in (1). The reference value V_{ref} is calculated from the set value of output voltage and the defined configuration of serial stabilizer. At a constant input voltage V_{in} and a constant load I_{load} for a constant value of V_{out}, the δ factor is constant. The changes in the input voltage and load are compensated by the change of the δ factor. Therefore, the initial value of the δ factor depends on the reference voltage, as shown in (2).

$$V_{out}(t)=f_1(\delta, V_{in}(t), f_{sw}, I_{load}) \tag{1}$$

$$\delta=f(V_{in}, I_{load}, V_{ref}) \tag{2}$$

where f_{sw} is the solar panel frequency.

From the equations above, it can be concluded that the output voltage $V_{out}(t)$ is dependent on the change of the reference voltage $V_{ref}(t)$, which is formulated as:

$$V_{out}(t)=f_2(V_{ref}(t)) \tag{3}$$

The schematic diagram in Fig. 3 shows that by changing the reference voltage value, V_{c1} and V_{c2} are also changed. Depending on the error amplifier voltage, the PWM impulses $V_{d1}(t)$ and $V_{d2}(t)$, which are triggers for the power switches, are generated. The serial converters send the voltage (V_{SP}, V_{WG}) and current (I_{SP}, I_{WG}) of the energy source to the microcontroller. The microcontroller calculates the reference value for serial converters and controls the power provided from certain sources. The battery charger controls the battery charging current according to the defined values for the selected batteries. When the battery reaches the charging voltage, the reference values of the serial controllers are changed and the battery charging current also decreases.

Possible situations occurring during the operation of the hybrid power supply system are as follows.

1) Operation on a renewable energy source with the limitation with which only the needed energy is taken. One of the renewable energy sources has more energies than that required by power consumers and the charging of the accumulative elements. If necessary, battery charging or maintenance is performed. This operation mode for hybrid power supply system can be expressed as:

$$P_{SP} > P_{load} + P_b \Rightarrow P_{out} = k_1 P_{SP} + P_b \quad k_1 < 1 \tag{4}$$

where P_b is the power required of the battery charging; and P_{out} is the output power.

2) Operation on two renewable energy sources with the limitation with which only the necessary energy is taken. Two renewable energy sources have more energies than that required by consumers and the charging of the accumulative elements. If necessary, battery charging or maintenance is performed. This operation mode is expressed as:

$$P_{SP} + P_{WG} > P_{load} + P_b \Rightarrow P_{out} = k_1 P_{SP} + k_2 P_{WG} + P_b \quad k_1 < 1, k_2 < 1 \tag{5}$$

3) Parallel operation of energy sources and accumulative elements. Renewable sources do not provide sufficient energy to consumers. The energy insufficiency is compensated by the accumulative element. This operation mode is expressed as:

$$P_{SP} + P_{WG} < P_{load} \Rightarrow P_{out} = P_{SP} + P_{WG} + P_b \tag{6}$$

An algorithm based on the fuzzy logic compares the measured values of the available power from all sources, the power required by consumers, and the status of the accumulative element. The control logic determines the source from which consumers will be supplied based on the obtained data. The voltage range within which consumers obtain the correct operation is defined prior to the beginning of the project.

Since it is difficult to predict the power obtained from renewable energy sources over time, a fuzzy controller is used to control the serial converters as well as the conditions for the charging and recharging of batteries or switching to battery power. A fuzzy inference system (FIS) is a used to map an input space to an output space using fuzzy logic. An FIS attempts to formalize the reasoning process of human language using fuzzy logic. Direct methods such as those developed by Mamdani and Sugeno are the most commonly applied. Mamdani method is used in applications owing to its simple "min-max" operation structure and its usage as a fuzzy inference method. Finally, such a control system obtains smooth transitions in power distribution from one source to another. Using the fuzzy controller, the state of the renewable energy source and batteries can be adequately defined. Based on this state, through a set of fuzzy rules, the control of the serial converters and battery chargers is defined. The fuzzy controller scheme shown in Fig. 4 has three inputs and three outputs. There are three member functions for each input and output. The available power from the solar panel, WG, and the capacities of the batteries are the inputs. The outputs are the control signals for the serial converters and the battery charger. The outputs from the fuzzy controllers for serial converters are positive because there is a one-way power flow. The output of the fuzzy controller for the battery charger can be both positive and negative. The member functions are triangular and trapezoidal types, and the maximum member function corresponds to the medium power of a renewable energy source.

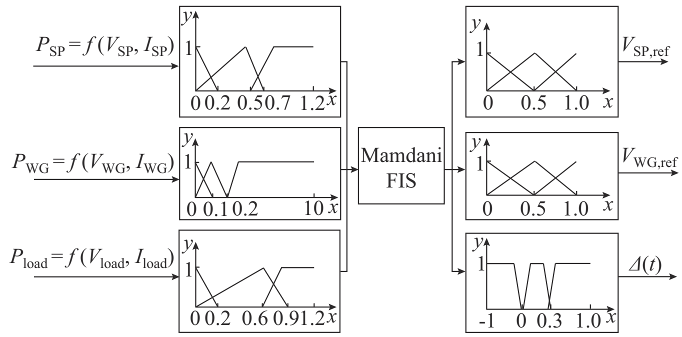

Fig. 4. Equivalent scheme of fuzzy controller.

The fuzzy set has 12 rules. During the defuzzification process, the centroid method is used to calculate the center of gravity (COG) of a particular membership function area. Averaging in the centroid method dilutes the control action and makes the controller less sensitive to minor variations [28]. The reference voltage is controlled by the output of the fuzzy controller; thus, a renewable energy source with more power provides greater power for the consumer. The power from both renewable energy sources is distributed so that it covers the consumer needs and provides power for charging or maintaining the batteries depending on their capacities. The control module provides a balanced use of the available energy from renewable energy sources. Additional power is taken from the battery power supply to compensate for the power deficiency for cases only in which the power from renewable energy sources is insufficient to power the consumers.

IV. Practical Realization of Hybrid Power Supply System

The specification of our PHPSS setup (shown in Fig. 2) consists of a 48 V/400 W solar panel, a small 5 kW WG (with rectifier), a 24 V/200 Ah battery, two custom-designed programmable DC/DC converters, and a novel controller based on fuzzy logic developed and produced at the Institute of Serbia.

The solution and experimental setup are shown in Figs. S1 and S2 in Supplementary Materials, respectively. Two renewable energy sources, a solar panel, a WG, and one chemical source (i.e., an accumulator battery) are connected. The power supply system ensures a reliable and uninterrupted power supply for consumers.

The electric current required by consumers is approximately 7.3 A, and the electric current of charging the battery is 2.7 A. During the measurement, the power could be obtained from the solar panel,which changes with the different lighting. To maintain a constant output power, the reference value of the serial converter with a connected WG is changed. In this way, the consumer voltage is maintained within the range of the allowed values.

This process is automatically performed using a control circuit based on a fuzzy controller. During the testing, the WG produces more energy than that required to compensate for the solar panel energy shortage, and the surplus energy is used to charge the battery. The rating of battery charging current is defined by the battery selection (typically 10% of the accumulator battery capacity value).

The reference value of the serial converter to which the WG is connected is adjusted so that the total current of the solar panel and the WG is equal to that required by consumers and charging the accumulator battery. The battery charging current only exists until the battery voltage reaches the maximum voltage of the charged battery V_{boost}, and then decreases to the accumulator battery maintenance current.

The measured values of the input and output currents of the serial converters as well as the set reference values of the renewable energy sources are given in Table I for the configuration shown in Fig. S1 in Supplementary Materials and are in accord with the operation of the fuzzy controller shown in Fig. 3.

TABLE I
MEASURED VALUES ON NOVEL PHPSS WITH SERIAL CONVERTERS (VOLTAGES AND CURRENTS)

V_{out} (V)	I_{out} (A)	I_b (A)	V_{SP} (V)	I_{SP} (A)	V_{WG} (V)	I_{WG} (A)	$V_{SP,ref}$ (V)	$V_{WG,ref}$ (V)	$I_{SP,out}$ (A)	$I_{WG,out}$ (A)
27.40	9.86	2.71	68.72	0.43	50	5.08	2.315	2.323	0.20	9.36
27.38	9.89	2.70	68.04	0.84	50	4.51	2.315	2.320	0.90	8.99
27.37	9.86	2.70	67.32	1.30	50	3.80	2.315	2.317	2.02	7.84
27.37	9.98	2.71	56.38	1.74	50	3.23	2.315	2.314	3.10	6.88
27.37	9.88	2.72	65.50	2.21	50	2.72	2.315	2.313	3.99	5.89
27.36	9.86	2.70	64.68	2.73	50	2.05	2.315	2309	5.06	4.80
27.35	9.80	2.72	64.00	3.24	50	1.40	2.315	2.310	6.10	3.70
27.35	9.80	2.71	62.41	3.00	50	0.81	2.315	2.304	7.20	2.60
27.35	9.92	2.70	60.35	4.50	50	0.25	2.315	2.298	8.40	1.52
27.35	9.90	2.70	59.35	4.83	50	0	2.315	2.290	9.90	0

The the output current v. s. measured reference voltage for the serial converter to which the WG is connected is shown in Fig. 5. The reference voltage of the serial converter ranges from 2.290 to 2.323 V. Figure 6 shows the input and output currents v.s. the reference voltage values for the converters.

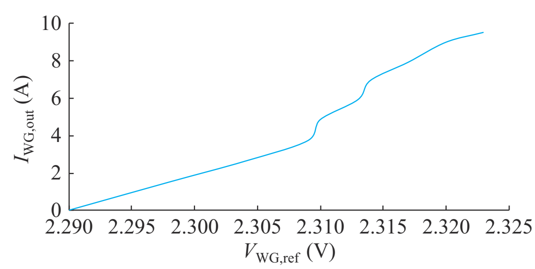

Fig. 5. Output current $I_{WG,out}$ v.s. reference voltage of DC/DC converter in branch of WG.

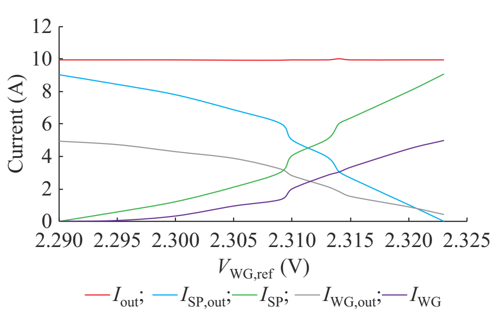

Fig. 6. Diagram of input and output currents v.s. reference voltage measured on serial converters.

The recorded voltages and currents for the consumer and the accumulator battery in transient modes (i. e., switching from a renewable power source to the accumulator battery) are shown as follows.

The waveforms of the accumulator battery currents and voltages charged by solar panel and WG are shown in Fig. 7. While charging with a constant current, the battery voltage slightly increases.

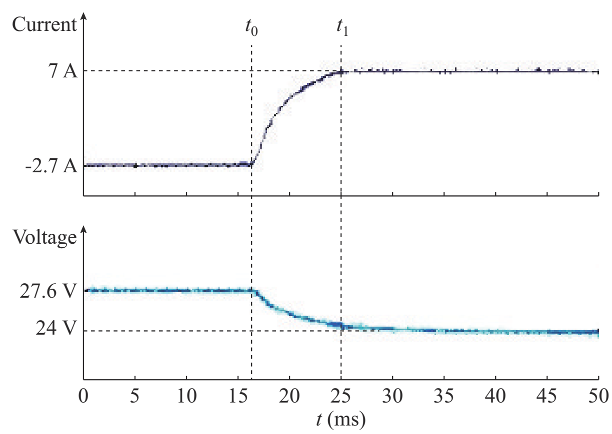

Fig. 7. Battery voltage and current charged by solar panel and WG at the same time.

If the solar energy is sufficient, both the consumers and the accumulator battery are powered by the solar panel. When the solar panel and WG do not provide energy, the consumers are supplied from the accumulator battery. The battery current changes its direction, and the battery is discharged. At the same time, the battery voltage decreases.

The battery is charged with a constant current of 2.7 A. When the solar panel is not illuminated (at the moment t_0) and the WG does not generate power, the consumers are powered by the battery. When the battery takes over the role of the power supply, the voltage on the battery is close to that at which the constant current charging ends (V_{boost}= 27.6 V), and the battery voltage is reduced for 18 ms at a nominal value of 24 V as shown in Fig. 7. During this period, the transition from primary to auxiliary (battery) power is smooth and does not affect the consumers.

The battery current changes its direction and increases until it reaches the value the consumer required. At time t_1, the battery discharging current is equal to the current of the consumer and is approximately 7 A. When solar panel lighting gradually declines, the renewable power source does not provide sufficient power for the consumers. The battery voltage and current charged by the solar panel are shown in Fig. 8.

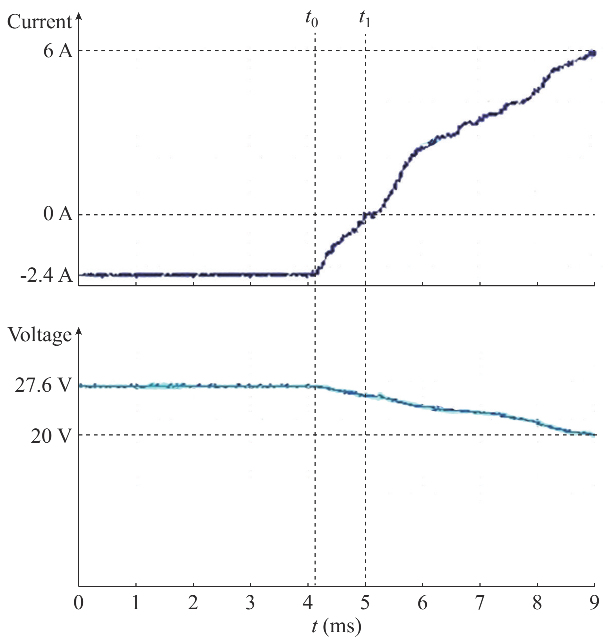

Fig. 8. Battery voltage and current charged by solar panel.

Under a lack of energy, additional power required for the customers is provided from the battery source. During the transition period from t_0 to t_1, when the solar panel lighting gradually declines, the battery compensates for the power leak.

Although there is sufficient energy produced by the solar panel, the battery is charged with a constant current (up to t_0), and when the illumination is reduced, the battery charging current decreases. The battery current at t_1 is equal to 0 A, and its direction is then changed and it flows toward the consumer.

The scenario in which consumers are powered by the battery and then by the renewable energy source is shown in Fig. 9. The power of the solar panel increases from t_0, and the solar panel takes over the supply to the consumers at t_1. When the solar panel provides sufficient power, it powers the consumers and charges the battery in accordance with the available power. Consumers always receive power, and the transition from one energy source to another has no effect on the consumers.

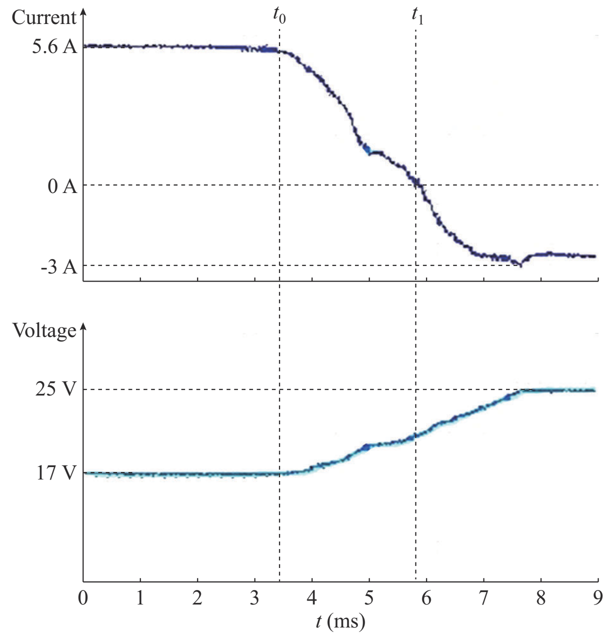

Fig. 9. Battery voltage and current of discharging when consumers are powered by battery and then by renewable energy source.

The realized hybrid power source is designed for a Telecom mobile station with a changeable power consumption at 24 V. A few watts of power are consumed in sleep mode and up to 200 W in active mode.

The maximum power point (MPP) incremental type of solar and wind power is tracked by measuring the input and output voltages as well as the currents on serial DC/DC converters (boost type) placed in branches with renewable solar and wind sources (the input in the fuzzy controller is the difference between two successive samples of output power).

The total maximum value of the solar panel power occurs at 32 V/14 A (400 W panel) and 120 V/45 A for the WG.

V. Discussion

The advantages of our PHPSS are based on the implementation of fuzzy logic. The processor considers the input power from the renewable energy sources and the output power required by the consumers. The processor then calculates the V_{ref} value for each renewable energy source to yield the maximum power. If the maximum wind power energy set by $V_{WG,ref}$ of the first serial converter is insufficient to fit the power required by the consumer, the solar energy set by $V_{SP,ref}$ for the second serial converter adds its maximum power. In the worst-case scenario, when both renewable energy sources add an insufficient amount of the maximum power, the battery source adds the "missing part" of the energy and the power required by the consumers is covered during the period of low-power production by the renewable energy sources.

The fuzzy controller based on Mamdani fuzzy logic is described in Section III, and its implementation is given in Fig. 10.

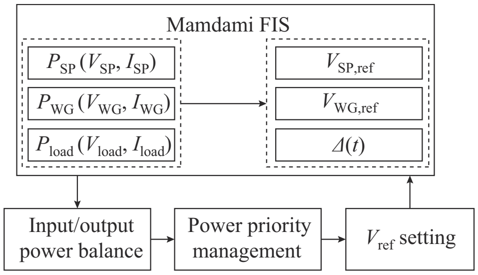

Fig. 10. Modification in Mamdani FIS logic.

The implementation of a fuzzy controller in this application enables better power monitoring using power balancing, power priority, reference voltage V_{ref}, the maximum battery saving, and fast adaptation to a changable load to maintain a voltage drop during transition periods within the range of allowed values. The block of input and output power balance calculates the available power from renewable energy sources, DC/DC converted power, power for battery charging, and current power consumption of the consumer (Telecom). The block of power priority management has a wireless connection with the PC in the office and serves to monitor the PHPSS states, governing using priority actions at low battery voltage, changing the maximum power if needed. The block of V_{ref} setting governs the maximum power temporarily (for example, 10 min each).

The realized PHPSS with a fuzzy logic controller has a small voltage drop and fast adoption to transient states. The maximum efficiency of energy conversion η_{max} is compared in Table II with other hybrid power systems such as a PV with maximum power point tracking (MPPT) charging controller (perturbation and observation algorithm) [11], a system with PV/WG/FC [12], [25], and PV/WG [14], [16].

TABLE II
COMPARISON OF HYBRID POWER SOURCES

Type	Active power (kW)	η_{max} (%)	Reference
PV/WG	0.24	75-85	PHPSS (our prototype)
PV	0.24	80	[11]
PV/WG/FC	1.00	70-80	[12]
PV/WG/FC	10.00	60-80	[25]
PV/WG	100.00	64-82	[16]

The stand-alone PHPSS like ours can be compared with those systems [18], [19], [24], where wind-solar/battery stand-alone systems are also reported. Many hybrid systems have a larger power designed for domestic and residential consumers, where the requirements are not based primarily on a high energy quality and high conversion efficiency [29], [30].

The proposed PHPSS can be compared with the solution in [24], where neural/fuzzy logic is applied. We reach their performances and maintain a voltage drop in the transition periods within the range of allowed values in the worst-case scenario where the wind-solar contribution together is insufficient, and the battery is activated to provide "missing energy" to the output of the system, as shown in Fig. 11. Figure 11 shows the output currents in the worst-case scenario of hybrid power source.

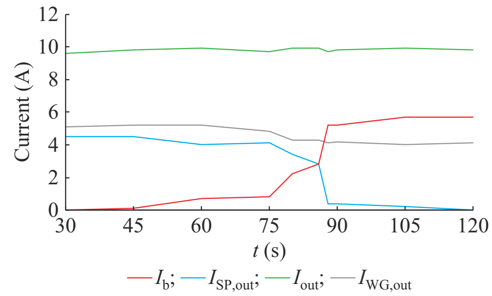

Fig. 11. Output current in the worst-case scenario of hybrid power source.

The output currents in Fig. 11 are measured under real conditions in the remote Telecom locations in the mountainous area, where the proposed PHPSS is exploited as a prototype.

Examples of planning, simulation, and optimization of hybrid power systems with three or more renewable energy sources such as those reported in [31]-[35], point out that this problem has been addressed to date. A more expensive method is to realize the prototype. This motivates us to develop our PHPSS with a fuzzy logic controller and two serial DC/DC programmable converters to work synchronously in parallel.

The prototype of the hybrid power solution during the first year of operation under real conditions in remote areas does not exhibit any uncertainty or deviation from the values presented above. The efficiency of the hybrid power supply depends on several conversions of renewable energy sources.

VI. Conclusion

The power supply system with a fuzzy logic controller can be applied to power telecommunication equipment in remote areas, where primary electro-distribution power supply is unavailable. The described PHPSS enables the control of two serial converters to which different energy sources are connected. By monitoring the input and output parameters of the energy sources and consumers, the microprocessor controls the operation modes. The energy available from renewable energy sources is not always predictable. Depending on the availability of energy from different sources, consumer needs, and batteries, the balanced use of available energy and partial recharging of the battery are necessary. The maximum efficiency of energy conversion varies from 75% to 85%.

In this study, an electronic solution is presented for the connection between two renewable energy sources and a rechargeable battery. To perform fast changes in energy use from different energy sources and smart energy management, a fuzzy logic controller is applied. Battery charging depends on the energy available from renewable energy sources and the energy required by consumers. The hybrid power supply system is dimensioned based on the power necessary to supply the consumers and the battery charging. The hybrid power supply system can react promptly in the case of a change in power provided by different energy sources.

The full system operates based on a change in the power source (i.e., from one source to another) or using a battery, and is not sensed by the consumer, e.g., by the power supply equipment. It is proven that the controller does not allow higher power supply (voltage or current) variations during transitions from one source to another. We expect the wide use of solutions for hybrid power supply systems with fuzzy logic controllers utilized in remote areas and in mobile equipment applications.

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