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Hybrid Uninterruptible Power Supply System for Irrigation of Vegetable Crops

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Abstract: The paper presents the realization of a hybrid and uninterruptible power supply system based on green or renewable energy sources (solar and wind) which is used for irrigation of vegetable crops on the "smart land" at the location of the town Belegiš, which is located in the immediate vicinity of Belgrade and on the side of the Danube River. Within the power system are realized the photovoltaic power plant with an output AC power of 8 kW, the wind generator with a power of 0.5 kW and battery bank 48Vdc/720Ah. This three of power supplies are as primary power sources, while a diesel electric generator (DEG) with a power of 7.5 kW, is one auxiliary power source. In addition to this hybrid and uninterruptible power supply, a system for smart management for irrigation has been implemented. At the end of the paper will be present the experimental results obtained during the exploitation.

Keywords: green energy, renewable energy sources, power supply, hybrid power, agriculture, irrigation

1. Introduction

The biggest problem facing humanity globally at the moment is the lack of natural resources for energy production. Renewable energy sources (RES) and their reserves are the main “driving wheel” of survival in the modern age. The increasing demand for electrical power and the trend towards it require energy devices that can be used to generate, distribute, conversion and store energy. Millions of people in small villages in developing countries currently have no electricity supply. In many cases, the extension of the power grid is impractical due to the highly dispersed population and/or due to the geomorphological features of the terrain where the population is settled.

Therefore, relatively small, independent energy systems at the level of smaller settlements and villages become the most acceptable option [1]. In these cases, an important place is occupied by the so-called hybrid power supply systems, which contain numerous power electronics converter elements (chargers, inverters, bidirectional rectifiers, etc.), as well as battery storage elements or electrical energy stores [2].

It should be noted that in the case when the energy level from RES (usually solar and wind source) is low (and) or when the battery bank capacity is low (or at discharged battery when is not possible to provide power to the consumer) the power supplying is taken over by diesel electric generator (DEG) or gasoline electric generator (GEG) [3-5]. The use DEG (or GEG) leads to pollution of the environment, making noise and does not fit into agricultural systems for the production of "organic food“. Therefore, these generators are used in extreme case of emergency. In this case, it is necessary to use automatic transfer switch (ATS) in order the consumers switch from the main DC/AC power converter (inverter) of the hybrid AC power supply system to the “back-up” power supply system based on DEG or GEG, and vice versa.

Agricultural irrigation systems are largely dependent on power grid, but in cases where the power grid is unavailable or intermittent character, hybrid "off-grid" power systems are practically the only solution. Solar energy in combination with wind energy are one of the most commonly used hybrid energy sources for various purposes, which relate to the application and improvement of agro-technical measures in irrigation systems.

As shown in Fig.1, the key advantage is the fact that in periods when there are lower intensities of solar radiation (late autumn, winter or early spring), wind energy dominates. Also, in the summer period (which otherwise implies the dominant energy of the sun), especially in mountainous areas, but often in plains, at night when there is no solar energy, wind energy becomes dominant.

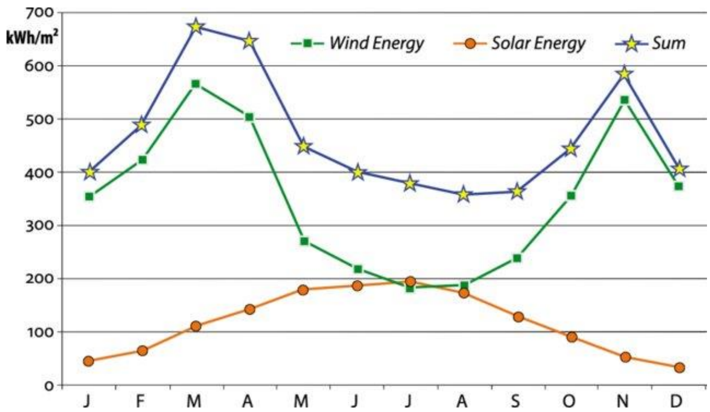

Figure 1. Annual of average (by month) course of solar and wind energy in Belgrade from 1961. to 1990. (Wind at the height of 100m, solar at the surface [6]

This paper present practical realizations “off-grid“ hybrid and uninterruptible power supply system which were used for irrigation of vegetable crops and for management of agricultural smart land a plot of 10 hectares on a private agricultural property in the town of Belegiš.

2. Description of Agriculture Smart Land Belegiš

The functional scope of the "Smart Land" plant for remote monitoring and management of agricultural production on an open agricultural plot in Belegiš is shown in Fig.2.

The key parts of this system are: (1) entrance to the protected space "Smart Land" farm, (2) an artesian well including a pumping station with a distribution cabinet and a base station, (3) mobile solar electrical generator *Mobi Sun* – Pro Energy, (4) stationary PV systems (5) mini wind turbine, (6) digital meteorological station, (7) DC combiner box, (8) submersible water pump, (9) water filter, (10) reservoir for liquid fertilizer and phyto-protective preparations, (11) pump check valve, (12) electromagnetic valve of irrigation system, (13) video surveillance system, (14) auxiliary economic facility, (15) GSM/GPRS antenna, (16) human-operator with personal device, (17) fence of core „Smart Land“ , (18) irrigation system sprinklers, (19) temperature and humidity sensors (in the air and the terrain) (20) pH sensors of the terrain, (21) Irrigation system pipeline, (22) Electrical cable installations, (23) control lines, (24) land that is cultivated in the traditional way/ land that is cultivated using the “Smart Land” system.

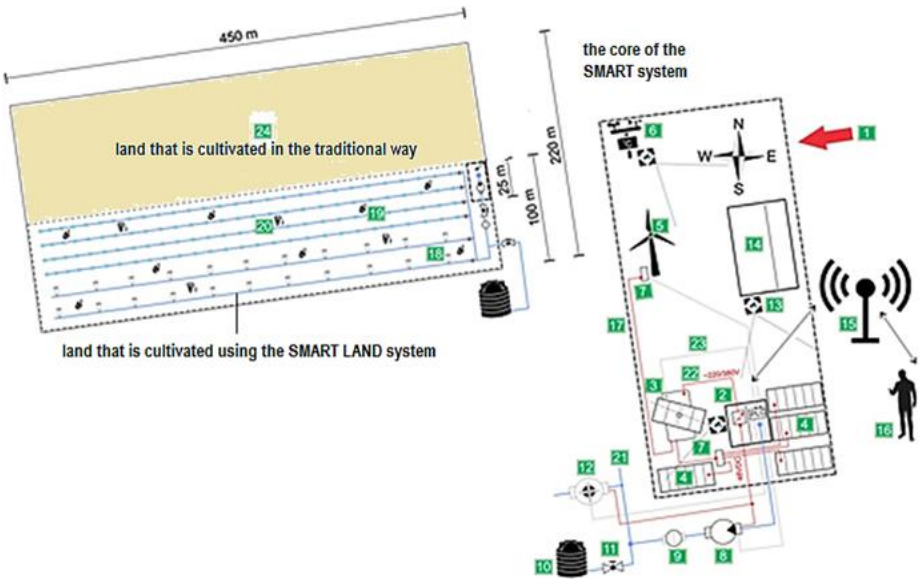

Figure 2. Functional scope of the agriculture "Smart Land" Belegiš [7]

Drone footage of the "Smart Land" system and hybrid uninterruptible power supply system for irrigation and remote control on the "Belegiš" plot is displayed in Fig. 3.

The plot and the hybrid power plant based on RES were depicted in Fig. 3(a). The screenshot on Fig. 3(b) shows the essential components of the power system: ground-mounted PV panels, wind generators, battery banks, and mobile solar generators (MSG.

Figure 3. The drone shoot of the "Smart Land" and hybrid power for irrigation and remote management on the plot "Belegiš; (a) view of the plot (above) and view of the hybrid power plant based on RES (below), (b) disposition of hybrid power

3. Description of Hybrid Uninterruptible Power Supply

Principal electrical block diagram of the "off-grid" hybrid and uninterruptible power supply of the "Smart Land" "Belegiš" with remote monitoring and management system are given in Fig.4.

Within this system are realized the PV power plant with an output power of 8 kW, the wind generator with a power of 0.5 kW and battery bank of 48Vdc/720Ah, as primary power sources and a DEG with a output power of 7.5 kW as an auxiliary i.e. "back-up" power source. In addition to this power supply system, a system for remote management of irrigation and smart management of land has been implemented [8].

The hybrid power supply ensures powering AC regulated drive of the electric motor of the submersible pump i.e. the frequency regulator (FR). The drive electric motor of the pump is three-phase asynchronous, rated voltage 3x400/230V, 50Hz, maximum input power P1=4.8kW and nominal speed 1450 rpm. In accordance with the previous requirements for the drive motor of the irrigation pump, a FR with a maximum output power of 5.5kW was implemented.

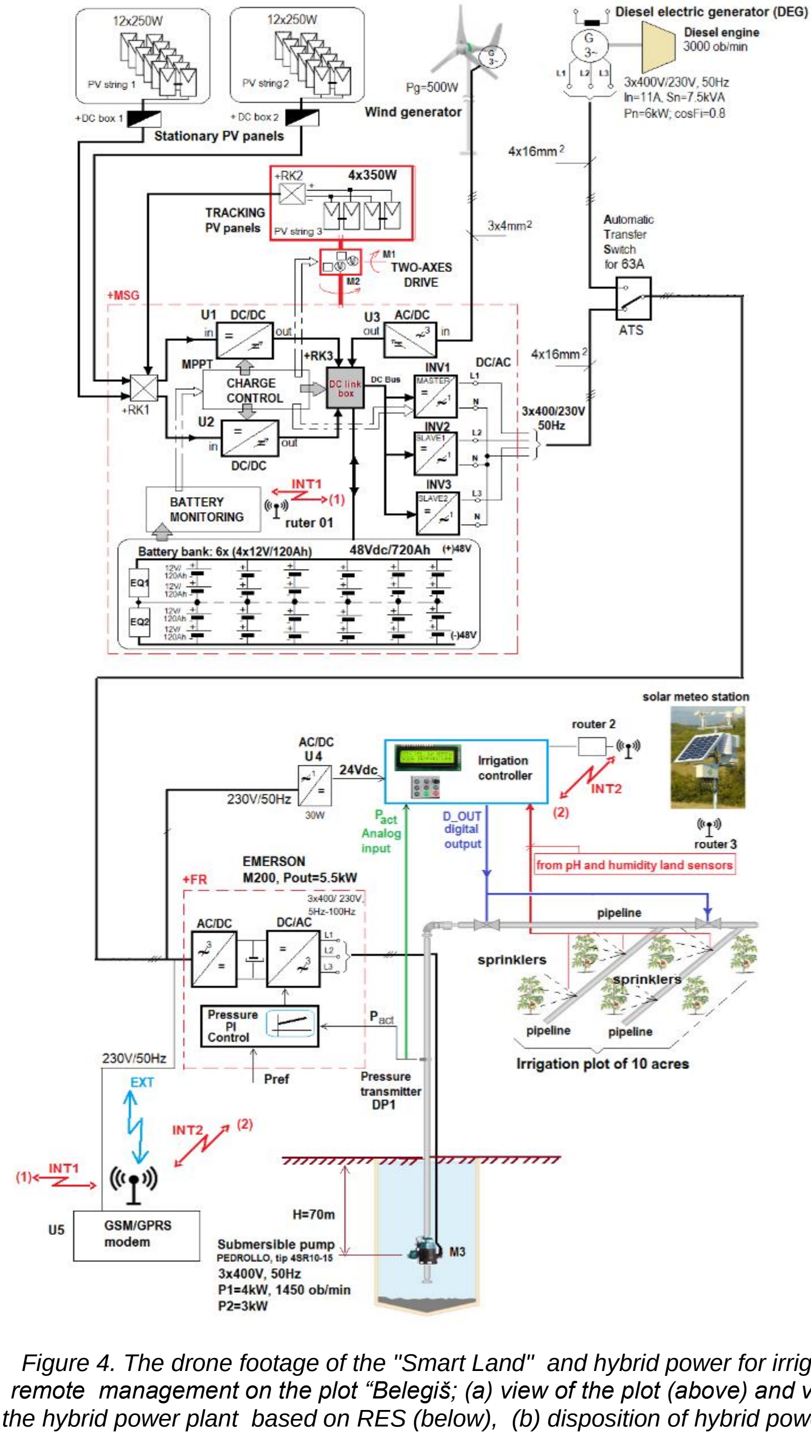

Figure 4. The drone footage of the "Smart Land" and hybrid power for irrigation and remote management on the plot "Belegiš; (a) view of the plot (above) and view of the hybrid power plant based on RES (below), (b) disposition of hybrid power

As part of this system, a control circuit for pressure regulation was realized (PI pressure regulator was implemented) in the pipeline with sprinklers, which provided irrigation of the land on the given plot. The pressure sensor DP1, range 0÷10bar, manufactured by WIKA, is used as pressure feedback. As a back-up source of three-phase power supply, a DEG was used, with a maximum output power of about 6kW at a rotational speed of about 3000 rpm. DEG is used exclusively in the mode when the power from RES is significantly reduced (in the case when there is no wind and solar insolation) and (or) when the battery bank is discharged below the discharge depth of 80%.

In the event of a complete discharge of the battery bank and reduced power from the RES, automatic switching of the three-phase power supply to the three-phase power supply from the DEG is foreseen by means of an automatic transfer switch (ATS). In this way, in addition to the hybrid power, and the uninterruptible power supply of the consumer system (primarily the irrigation system) is provided.

Table 1 provides a list of consumers on this agricultural plot in the vegetable crop irrigation system.

Table 1. *List of consumers on the Smart Land plot Belegiš*

CONSUMER	**Power(W)**
AC Pump drive (pump+ frequency converter)	5300
Irrigation controller	110
Video-surveillance system	100
Wireless routers (2 pcs.)	30
GSM/GPRS modem (2 pcs.)	60
Electronic circuits in „*stand by*“ mode	100
ΣP	**5700**

4. Experimental results

This chapter presents some key experimental results related to remote monitoring and control, as well as balances of produced and consumed electricity on a daily basis for typical days in the month of July 2023.

The experimental results were obtained on the basis of data logging that was achieved through measuring acquisition module i.e. through the CLOUD platform where the VRM portal is available:
https://vrm.victronenergy.com/login

Fig.5 shows a graphic representation of the power flows in the hybrid power supply system of the 5.5kW pump aggregate in the vegetable crop irrigation system for July 4, 2023. The graphic display was obtained based on loading data from the VRM portal.

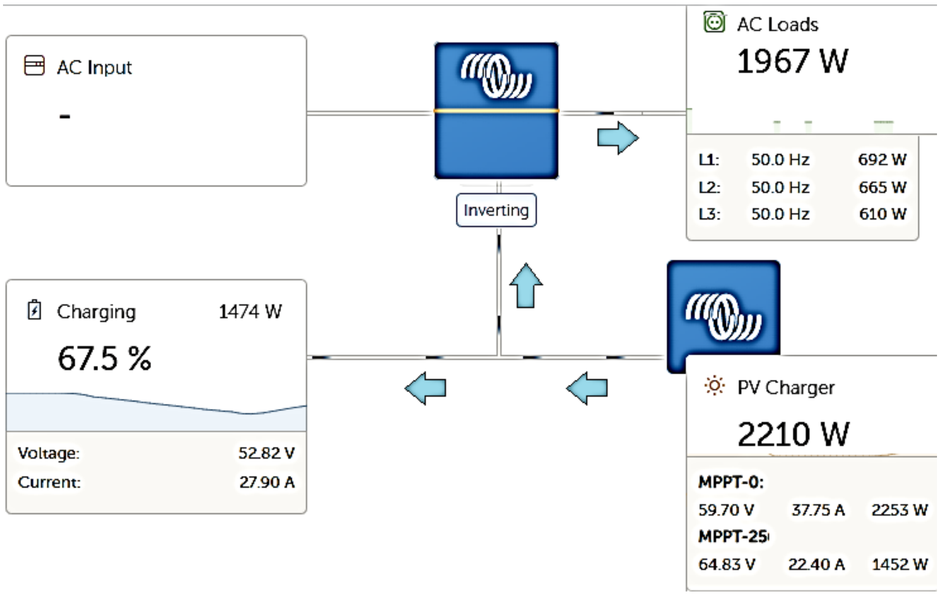

Figure 5. Graphic representation of power flows in the irrigation system on the plot in the town of Belegiš

It is observed that the AC input is not active (AC input=0), which means that the DEA was not working in the system. At the moment when the energy state of the system was loaded (the data refers to the time 12:00h), the current production from the PV panels was about 3700W.

The output of MPPT charger-1 was 2253W (at voltage 59.7V and current 37.75A), while the output of MPPT charger-2 was 1452W (at voltage 64.83V and current 22.40A).

A part of this total power of 3700W, more precisely in the amount of 1474W, is given to the battery bank (at a battery voltage of 52.82V and a battery charging current of 27.9A). The state of charge of the battery bank SOC% at this moment was 67.5%.

The part of the power that is delivered to the DC/AC converter (inverter), taking into account all the losses that exist in the DC distribution of the hybrid system, is 2210W. At the output of the inverter, that is, at the AC load, there was a three-phase power in the amount of 1967W. The power distribution by individual phases was: phase L1-692W, phase L2-665W, and phase L3-610W.

Fig.6 shows characteristic data of energies which are obtained from the VRM portal. The energies are expressed in kWh on July 4, 2023, and for the time interval from 00:00h to 13:00h: (1) consumption of energy, (2) production of energy from PV plants and (3) energy state of the battery. In addition to this, the state of charge (SOC) of the battery bank is given expressed in %, i.e. the SOC% parameter is given.

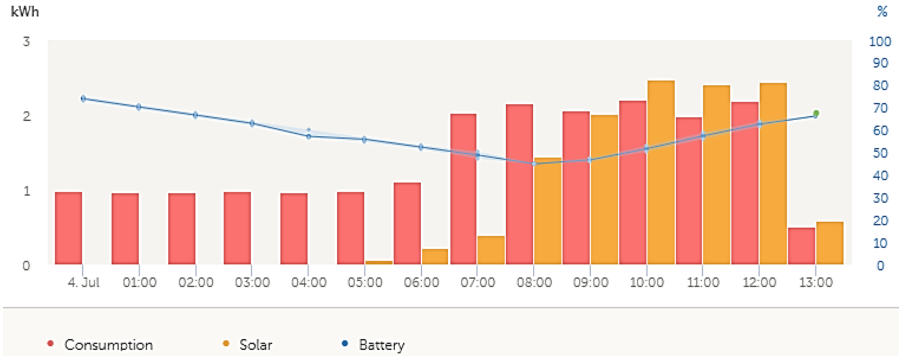

Figure 6. Data history (consumption-solar-battery) on energies expressed in kWh for July 4, 2023, for the daily time interval from 00:00h to 13:00h.

Fig.6 shows characteristic data, i.e. energy expressed in (kWh) on July 9, 2023, for the all-day interval from 00:00h to 23:00h, for the following energies: energy consumption, energy production from solar panels and the energy state of the battery. In addition, the state of charge of the battery bank is given expressed in %, i.e. the SOC% parameter is given.

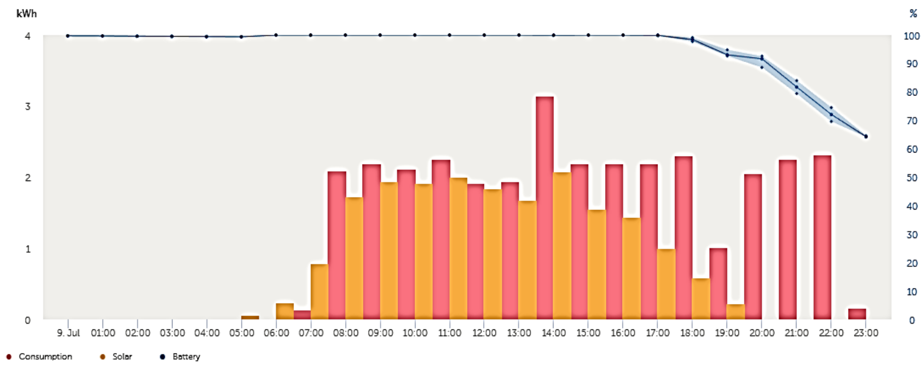

Figure 7. History of data (consumption-solar-battery) on energy expressed in kWh for July 9, 2023, in the time interval from 00:00h to 23:00h.

In the Interval from 08:00h to 18:00h, the power consumption was about 2.5kW, with one clearly expressed peak at 14:00h when the power was 3.5kW. In the mentioned interval, production from solar panels largely met all needs, and the state of the battery bank, which was previously charged to 100%, did not significantly change until 18:00 when the SOC% began to decrease because production from solar panels was significantly reduced.

For this case, the very interesting part of the interval from 20:00h to 22:00h, when irrigation of certain crops was carried out during the night period (farming requirements were such). In this interval, the battery bank assumed the role of the main energy source, so that around 11:00 p.m. the state of charge of the battery was SOC%=60%. In this case, the total consumption was 32kWh, while the production from the solar panels was 19kWh, and the difference of 13kWh was compensated from the battery bank.

The continuation of the irrigation regime was achieved on July 10, 2023, so Fig. 8 shows the characteristic data, i.e. energy expressed in (kWh) on July 10, 2023, for the interval from 00:00h to 19:00h.

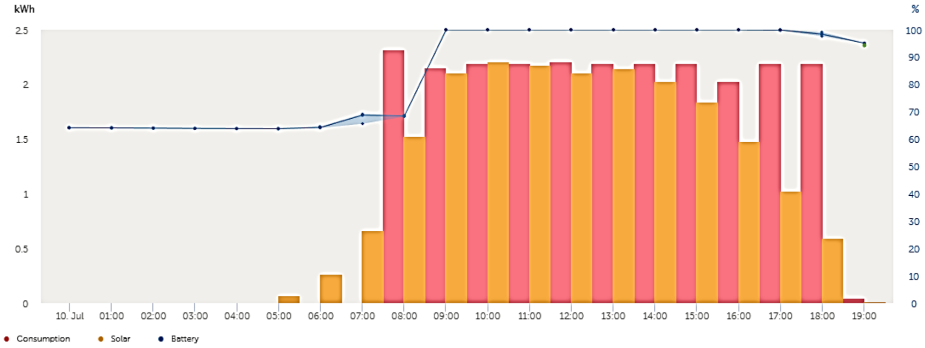

Figure 8. History of data (consumption-PV - battery) on energy expressed in kWh for July 10, 2023, in the time interval from 00:00h to 19:00h.

From the diagram in Fig.8, it can be seen that in a relatively short time interval from 08:00 a.m. to 10:00 a.m., the battery bank was recharged from a state of charge of SOC%=65% to a state of charge of SOC%=100%.

A slight drop in the state of charge of the battery is observed after 17:00h, when there was a weakening of the intensity of solar radiation, and the requirements for irrigation remained approximately the same as for the past time intervals (approximately constant power consumption of 2.5kW).

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Kratak sadržaj: U radu je prikazana realizacija hibridnog neprekidnog sistema napajanja zasnovanog na zelenim ili obnovljivim izvorima energije (solarna i vetar) koji se koristi za navodnjavanje povrtarskih kultura na „pametnoj parceli“ na lokaciji mesta Belegiš, koji se nalazi u neposrednoj blizini Beograda i na obali reke Dunav. U okviru pametnog sistema napajanja su realizovani fotonaponska elektrana izlazne naizmenične snage 8 kW, vetrogenerator snage 0,5 kW i baterijska banka 48Vdc/720Ah. Ova tri izvora napajanja su primarni izvori napajanja, dok je dizel električni generator (DEG) snage 7,5 kW pomoćni izvor napajanja. Pored ovog hibridnog i neprekidnog napajanja, implementiran je sistem za pametno upravljanje navodnjavanjem. Na kraju rada prikazani su eksperimentalni rezultati dobijeni tokom eksploatacije.

Ključne reči: zelena energija, obnovljivi izvori energije, napajanje, pametna poljoprivreda, navodnjavanje

Hibridno neprekidno napajanje sistema za navodnjavanje povrtarskih kultura

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