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Optimum Selection based on the Energy Capacity between Different Types of Renewable Sources using a Controller

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Introduction

Many renewable source installations combine more than one energy sources. In that case, a selection has to be made based on two major criteria: economy and maximum provided power [1-4].

In our project we have an installation of photovoltaic panels and a wind generator, each with its own batteries. The optimum selection is made by a supervising controller. This supervising controller is issuing the appropriate command signals to the power electronic section and continuously the optimum energy source is selected to be connected to the electrical load. The other energy source is simply charging the attached batteries, until it is fully charged.

As an example at a windy and cloudy day, the wind generator will be connected to the load and the photovoltaic panel will be slowly charging its batteries.

The paper is divided into five parts, where the system parts are described: a) the wind generator, b) the photovoltaic panels c) the batteries d) the inverter and e) the supervising controller. The block diagram of the system is shown in Fig. 1.

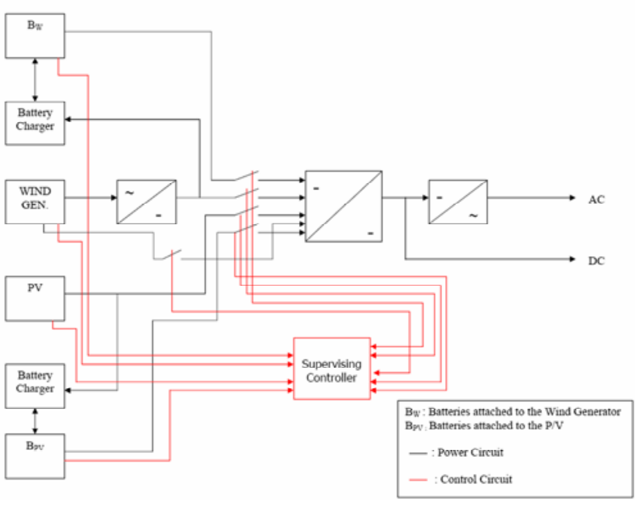

Fig. 1. Block diagram of the renewable sources and the supervising controller

Wind Generator

As the machine that converts the wind kinetic energy to electricity is used as the wind generator, the electric power will be significantly less than the wind power [5]:

$$P_{a/k} = C_p \frac{\rho}{2} V^3 As, \tag{1}$$

where $P_{\alpha/\kappa}$ – the provided power from the wind generator; ρ – the wind density (equal to 1,2 Kgr/m^3); C_p – constant less or equal to $\frac{19}{25}$; A – the area of the wind generator flaps ($A = \frac{\pi D^2}{4}$); V – wind velocity.

The C_p is called power factor. It has to be noted that it is not strictly the rotor's power factor, since it is referring to a total power impossible to be used even with an ideal propeller. The maximum C_p is $C_p = \frac{19}{27}$.

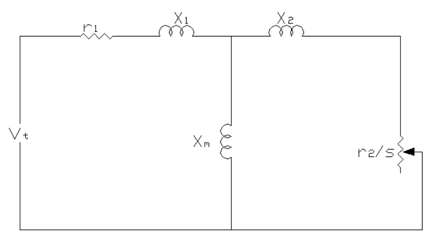

Fig. 2. The asynchronous generator circuit diagram (per phase)

In Fig. 2 the asynchronous generator circuit diagram (per phase) is shown. If ω_s is the stator's rotational velocity, ω_r the rotor's rotational velocity, then s is $s = \frac{\omega_s - \omega_r}{\omega_s} = \frac{n_s - n_r}{n_s}$, where n_s and n_r are respectively the rotations per minute, and $\omega_s = 2\pi \frac{n_s}{60}$ and $\omega_s = 2\pi \frac{n_r}{60}$.

From the above circuit diagram is yield:

$$I_2 = \frac{V_1}{R_1 + \frac{R_2}{S} + jX}, \quad I_m = \frac{V_t}{jX_m}, \quad I_1 = I_m + I_2 \tag{2}$$

$$T_e = \frac{3R_2}{\varpi_s s} I_2^2 = \frac{3}{\omega_s} \frac{V_t^2 \frac{R_2}{s}}{\left(R_1 + \frac{R_2}{s}\right)^2 + X^2}, \tag{3}$$

where $\omega_r = \frac{2\pi n_r}{60}$ – the angular velocity; T_e – the generator's electromagnetic torque (electric anti-torque); T_m – the wind generator mechanical torque, which is given by $T_m = \frac{1}{2} C_p p \frac{\pi R^2}{\omega_r} u_w^3$; the C_p constant is given in the wind generator's data sheets, as a function of the factor:

$$\lambda = \frac{\omega_r R}{u_w} = \frac{2\pi n_r}{60} \frac{R}{U_W} \tag{4}$$

In more detail for the asynchronous generator the electromagnetic torque T_e has a maximum (according to the circuit diagram):

$$T_{e\max} = \frac{1}{\omega_s} \frac{1.5V_t^2}{R_1 - \sqrt{R_1^2 + X^2}}, \tag{5}$$

which occurs for the drifting equal to

$$S_{\max T} = -\frac{R_2}{\sqrt{R_1^2 + X^2}} \tag{6}$$

The electric power produced will be

$$P_e = T_e \varpi_r = T_e (1-s)\omega_s \tag{7}$$

The wind velocity is continuously changing, so the $T\alpha_m$ is changing and as a result the wind generator is in transient state. For example, to any wind velocity increase in general there must be an increase of the rotational speed, even though there might be a C_p decrease. Since the generator operates with a drift less than S_{maxT} that is in the 1- S_{maxT} area, there will be an increase of the T_e and as a consequence a machine deceleration. So, if there will a stabilization on T_m the machine will enter a new balanced condition with a higher speed. On the other hand there will be an increase in the I_1 current. If the mechanical torque exceeds the T_{emax} (the maximum torque the generator can handle) and keeps it for quite a long the machine will accelerate over the S_{maxT} point. Operating in this area, the increase in speed will result a decrease of T_e and a higher machine acceleration. The machine has to be isolated and removed from the network, because the generator would be endangered by an overcurrent and the windgenerator of an overaccelaration.

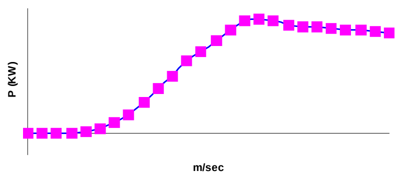

Fig. 3. The windgenerator power versus the wind velocity

It has to be noted that under vigorous wind velocity changes, all above could lead to continuous windgenerator coupling and de-coupling to the network. Even if the re-coupling is performed automatically and in a very short time, continuous coupling and de-coupling could result loss of the wind energy and furthermore will cause windgenerator fatigue.

If windgenerator electrical characteristics are known the produced windgenerator electrical power could be calculated using the above equations. Fig. 3 pictures a typical windgenerator power curve versus the wind velocity.

Electrical characteristics of the photovoltaic elements

A simplified model of a photovoltaic element is a current source controlled by a diode (as shown in Fig. 4). Based on this schematic the current produced by a photovoltaic element can be calculated :

$$\begin{cases} I = I_{sc}\{1 - K_1[\exp(K_2 V^m - 1)]\},\ K_1 = 0.01175 \\ K_4 = \ln\left(\frac{1+K_1}{K_1}\right);\ K_2 = \frac{K_4}{V_{oc}^m};\ K_3 = \ln\left[\frac{I_{sc}(1+K_1) - I_{mpp}}{K_1 I_{sc}}\right] \\ m = \frac{\ln\left(\frac{K_3}{K_4}\right)}{\ln\left(\frac{V_{mpp}}{V_{oc}}\right)} \end{cases};(8)$$

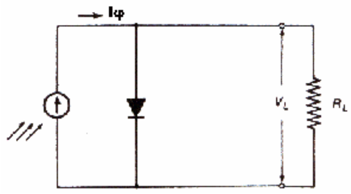

Fig. 4. A simplified photovoltaic element

When radiation and ambient temperature change, the following equations stand:

$$\begin{cases} \Delta T_C = T_C - T_{STC}, \\ \Delta I = a_{SC} T\left(\frac{G}{G_{STC}}\right)\Delta T_C + \left(\frac{G}{G_{STC}} - 1\right) I_{SC,stc} \\ \Delta V = -\beta_{ocT}\Delta T_C - R_S \Delta I, \\ V_{new} = V_{STC} + \Delta V,\ I_{new} = I_{STC} + \Delta I, \\ T_C = T_a + \frac{G}{800}(NOCT - T_{a,ref}) \end{cases} \tag{6}$$

The algorithm described in Fig. 6 is derived from the above equations and the Fig. 5.

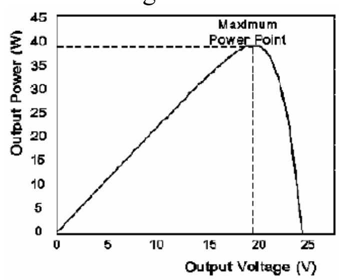

Fig. 5. Maximum power point monitoring

Batteries

The battery capacity (i.e. the charge stored) is measured in Ampere-Hours (Ah) and is equal to the product of the average current (I) the battery can provide (not depended by the battery voltage) multiplied by the time in Hours to the complete discharge (starting from the fully charged condition) [6]. Another useful magnitude is the stored electrical power (which depends on the battery voltage). For example a battery with a capacity of C=100 Ah, and an average voltage of V=12 Volts, has a nominal capability of storing electrical energy equal to 100 Ah x 12V = 1200 Wh=1,2KWh.

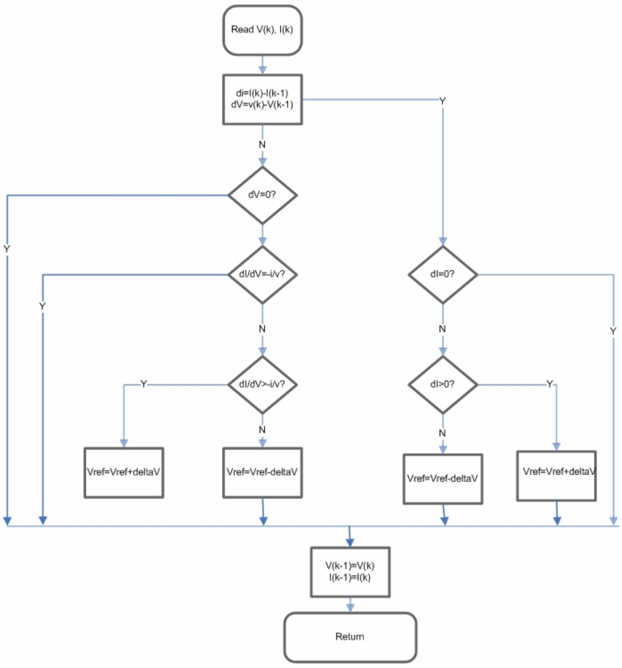

Fig. 6. MPPT algorithm

Thus, a battery with nominal capacity C_N, will have active capacity C equal to $C = \beta * C_N$ and the maximum electrical power able to be stored and recovered, in ideal conditions in each charge-discharge cycle is $E = C * V = \beta * C_N * V$, where β is battery discharge depth.

Consequently, if electrical energy needed is E, active capacity is C, the corresponding charging energy E_Φ will be $E_\varphi = \frac{E}{a}$, according to the previous equation giving the maximum energy that could be stored and recovered is $C_N = \frac{E_\varphi}{\beta * V} = \frac{E}{a * \beta * V}$. Battery charging could be administered using charge controller with MPPT function.

Controller's operation

The proposed algorithm for the overall controller is based on the following assumptions. At first the user has to enter following data: a) Windgenerator: 1) Input speed; 2) Output speed; 3) Power; 4) Selection of the electrical output (DC or AC); b) Photovoltaic cell: 1) Maximum power; 2) Operation voltage; c) Battery: 1) Operation voltage; 2) The maximum discharge; 3) Capacity.

The controller has the following assignment:

- Monitor the wind speed (using an anemometer);
- Monitor photovoltaic output voltage;
- Monitor the windgenerator battery voltage;
- Monitor the photovoltaic battery voltage;
- Set the windgenerator as DC or AC.

Afterwards the operation steps have to be set, from 0 to 4: 0 represents the 0 to 20% of the total energy source operation; 1 represents the 20 to 40% of the total energy source operation; 2 represents the 40 to 60% of the total energy source operation; 3 represents the 60 to 80% of the total energy source operation; 4 represents the 80 to 100% of the total energy source operation. Best energy source is assumed to be the windgenerator, then the photovoltaic cells, then the windgenerator batteries and finally the photovoltaic batteries.

Inverter's operation

The system's operation can be described more vividly by a realistic example: the conditions would be wind velocity just over 4 m/sec and there is sunshine.

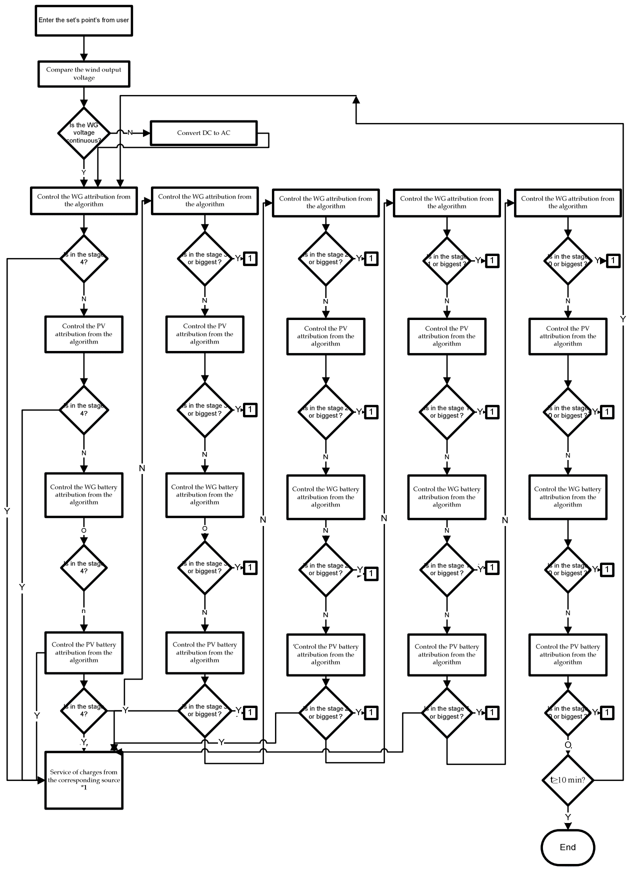

Fig. 7. The algorithm

The controller collects the wind velocity data from an anemometer and since it is more than 4m/sec, directs the wind generator output to the electric load. The windgenerator electric output has the following transitions:

1. The 220V/50Hz AC voltage through the AC-DC converter is converted to 24 Volt DC;
2. The charging controller, checks the battery voltage, if it is less than 20 Volts, then part of the windgenerator's power is used to charge the batteries. On the contrary (the batteries are charged) the total energy is directed to the load;
3. After that the DC voltage is less than 24V and is corrected using a DC-DC converter. Part of the output is used to the DC load (i.e. light);
4. Finally, the converted 220V/50Hz AC voltage supplies the AC load.

Due to the sunshine as mentioned before the photovoltaic panels produce DC voltage. This voltage is stabilized using a DC-DC converter and is used to charge the batteries, controlled by a charge controller.

In the case of wind stillness steps 2,3,4 are followed. In the case of wind stillness and cloudy then the steps 3 and 4 are followed. The controller selects each time the main power source, as described above. It has to be noted that the wind velocity and the battery charging voltage can be alter by the user as desired. The altering is achieved by changing the controller's program. Following the above data the algorithm (Fig. 7) is derived.

Experimental results

To test the described algorithm a program was developed on the MatLab Simulink. The inputs to the system are: a) wind velocity; b) photovoltaic primary voltage; c) battery voltage of the windgenerator; d) battery voltage of the photovoltaic panels.

In order to simulate the real conditions the inputs are fed with a random number generator. To implement the algorithm the functioning levels of each element is divided into four regions: 1) from 10-12 which represents the 85-100% level of operation; 2) from 8-10which represents the 70-85% level of operation; 3) from 4-8 which represents the 35-70% level of operation; 4) from 0-4 which represents the 0-35% level of operation.

The above limits are changeable according to the desired levels (depending on the selected criteria). The model is constructed using the if-then-else commands, in each subsystem.

Conclusions

The presented paper presents the theoretical study of an inverter in order to achieve the optimum power source based on financial criteria. This is proved to be achieved by following the presented algorithm.

The implementation of the algorithm in a proposed system equipped with the appropriate subsystems presents the ability of connecting four different power renewable sources as inputs and receive as output either AC or DC voltage.

The presented algorithm is user friendly to the average user and the installation cost reduction of a hybrid power source. The wider use of presented algorithm will minimize the overall costs and will promote the usage of the renewable sources.

Acknowledgements

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The forthcoming end of the fossil fuel era combined with the increase of energy consumption and with the dramatic expansion of the environmental problems, are leading our society to the one way use of the renewable sources of energy. Furthermore, attention has to be drawn on the energy saving and rational use. Full description of system selecting optimal renewable energy source is given. A complete study of each renewable source of energy will proceed. The system comprises a wind generator, a row of photovoltaic panels and their batteries. Both energy sources are driven to the system's inverter and the whole supervising is performed by a controller. Inverter's functional description and optimum energy source selection algorithm is presented. Ill. 7, bibl. 4 (in English; summaries in English, Russian and Lithuanian).

Д. Бандекас, Н. Вордос, К. Тарханидис, Л. Магафас, Г. Тсириготис. Выбор оптимального возобновимого источника на основе энергетической емкости используя контроллер // Электроника и электротехника. – Каунас: Технология, 2007. – № 8(80). – С. 9–12.

Анализируется полное описание системы, выбирающей оптимальный возобновимый источник энергии. Доставку энергии обеспечивает контроллер. Система состоит из ветрового генератора, солнечных элементов и батарей. Оба источника энергии соединены с инвертором системы. Представлено функциональное описание инвертора и алгоритм подборки оптимального источника энергии. Ил. 7, библ. 4 (на английском языке; рефераты на английском, русском и литовском яз.).

D. Bandekas, N. Vordos, K. Tarchanidis, L. Magafas, G. Tsirigotis. Optimalaus atsinaujinančio energijos šaltinio parinkimas remiantis energiniu pajėgumu ir naudojant valdiklį // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2007. – Nr. 8(80). – P. 9–12.

Nagrinėjamas išsamus optimalų atsinaujinantį energijos šaltinį parenkančios sistemos aprašas. Energijos tiekimą inverteriui kontroliuoja valdiklis. Sistema susideda iš vėjo jėgainės, saulės elementų ir jų baterijų. Abu energijos šaltiniai prijungti prie sistemos inverterio. Pateiktas inverterio funkcinis aprašas ir optimalaus energijos šaltinio parinkimo algoritmas. Tolesniuose tyrimuose bus nagrinėjami atsinaujinantys energijos šaltiniai. Il. 7, bibl. 4 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).