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# THE CONTROL PRINCIPLES OF THE WIND ENERGY BASED DC MICROGRID

G. Zaleskis, I. Rankis
Riga Technical University, Faculty of Power and Electrical Engineering, Institute of Industrial Electronics and Electrical Engineering,
12-1 Azenes Str., Riga, LV-1048, LATVIA
e-mail: genadijs.zaleskis@rtu.lv

According to the strategical objectives of the use of the renewable energy sources, it is important to minimise energy consumption of conventional power grid by effective use of the renewable energy sources and providing stable operation of the consumers. The main aim of research is to develop technical solutions that can provide effective operation of the wind generators in the small power DC microgrids, which also means wind energy conversion at as wider generator speed range as possible.

***Keywords:*** *energy resources, renewable energy sources, wind energy*

## 1. INTRODUCTION

The strategic objectives of the use of renewable energy sources can be reached by integration of the renewable energy sources, e.g., wind turbines. This way, the appropriate laws and regulations on the use of renewable resources and energy efficiency in buildings will be implemented. Political and ecological factors stimulate the development of the renewable energy. The main aim of the present research is to develop technical solutions that can provide effective operation of the wind generators in the small power microgrids, which means stable operation of the consumers and wind energy conversion at as wider generator speed range as possible.

According to the strategical objectives of the use of the renewable energy sources, it is important to minimise power consumption of conventional power grid by effective use of the renewable energy sources and providing stable operation of the consumers. This task can be decided by the use of the DC microgrid, which can operate synchronously with the conventional network and autonomously, ensuring energy supply to the decentralised consumers or in the emergency case.

According to the defined aim of the research, it is of special significance to provide an operative coordination of the main partners of wind energy based system – wind generator itself, the conventional three-phase network and an energy storage system for providing supply of consumers when wind power and energy of conventional network both are not available for some reasons. The energy storage system is an optional part and is not included in the present research. Solution of the defined tasks should be provided taking into account static and dynamic parameters of the systems involved considering its controllability.

The defined tasks are very topical for investigators of wind power based systems and some of their aspects are investigated in the papers [1]–[4], which propose applications of different approaches to solve the task of maximum wind power extraction. Therefore, it can be stated that the problem is topical and asks for efficient solutions.

## 2. PRINCIPLES OF THE DEVELOPMENT OF WIND ENERGY BASED DC MICROGRID

There are three main groups of microgrids depending on the bus voltage: DC based microgrid; AC based microgrid; DC and AC based microgrid [5]. The DC based microgrid topology is discussed in the present research. This choice is determined by the most efficient use of the renewables, which is achieved by reducing the conversion losses, and the ability to provide uninterrupted power supply [5]–[12]. The possibility of using the recuperated braking energy of the electrical drives is also taken into account. Due to this option, DC microgrid becomes popular in the industry sector [13]. All generating object and energy storages are connected to common DC bus in the DC based microgrid topology through the relevant converters [5]. It is appropriate to use a variable speed wind turbine with permanent magnet synchronous generator (PMSG) and full power electronics conversion in the DC based microgrid [14]. The energy storage system is not studied in the present research, so the principal scheme of the wind energy based DC microgrid with connection to the conventional AC grid is presented in Fig. 1.

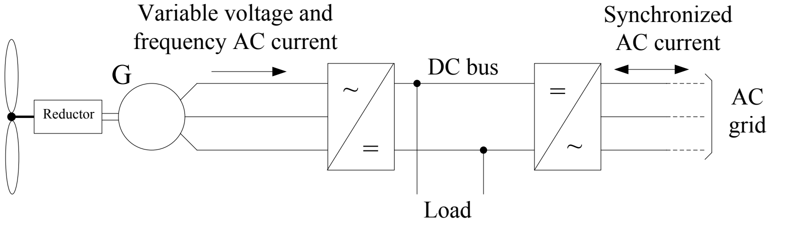


*Fig. 1.* The wind energy based DC microgrid with connection to the conventional AC grid.

Taking into account the power grid standard of the Republic of Latvia on 230/400 V and household connection types, there is a possibility to connect a microgrid to one- or three-phase AC grid. The connection to three-phase power grid is discussed in the present research. It can be implemented by the use of the active rectifier (active front-end) [15]; in this case, DC bus minimum voltage must be equal to rectified AC voltage peak value [16], which is equal to AC line voltage amplitude:

$$V_{d,\min} = V_l \cdot \sqrt{2} = 565\text{V}, \tag{1}$$

where $V_l$ = 400 V – line voltage r.m.s., V.

According to standard LVS EN 60038 [17], the rated DC bus voltage $V_{d,r}$ was accepted equal to 600 V.

## 3. PERMANENT MAGNET SYNCHRONOUS GENERATOR CONNECTION TO THE DC BUS

In accordance with the generator parameters, the use of non-inverting buck-boost DC/DC converter was prompted [1], [18], [19]. The control system of the converter is based on setting the wind generator optimal power curve and directly adjusting the DC/DC converter duty cycle [2]–[4]. The block diagram of the proposed system and principal scheme of the converter are shown in Fig. 2. The DC bus voltage is equal to:

$$V_d = V_{g,dc} \cdot \frac{D1}{1 - D2}, \text{V}, \tag{2}$$

where $D1$ – the duty cycle of the switch VT1;
$D2$ – the duty cycle of the switch VT2;
$V_{g,dc}$ – the output DC voltage of the generator.

Accepting the maximum value of $D2$ equal to 0.9, the generator output voltage is:

$$V_{g,dc}^{1} = 0.1 \cdot V_d, \text{V}. \tag{3}$$

At this generator voltage generator, output direct current must be:

$$I_{g,dc}^{1} = \frac{k_{dc} \cdot n}{R_g} - \frac{0.1 \cdot V_d}{R_g}, \text{A}. \tag{4}$$

At a low generator speed range, generator converter output current is:

$$I_1^1 = 0.1 \cdot I_{g,dc}^{1} = \frac{0.1 \cdot k_{dc} \cdot n}{R_g} - \frac{0.01 \cdot V_d}{R_g}, \text{A}. \tag{5}$$

The resistance $R_g$ characterises the internal resistance of the generator and the impact of commutation:

$$R_g = \frac{V_{g,dc,0}}{I_{g,dc,\max}} - \frac{P_{ref}}{I_{g,dc,\max}^2}, \Omega. \tag{6}$$

At $I_1 = 0$, generator speed is:

$$n_0 = \frac{0.1 \cdot V_d}{k_{dc}}, \text{rpm}. \tag{7}$$

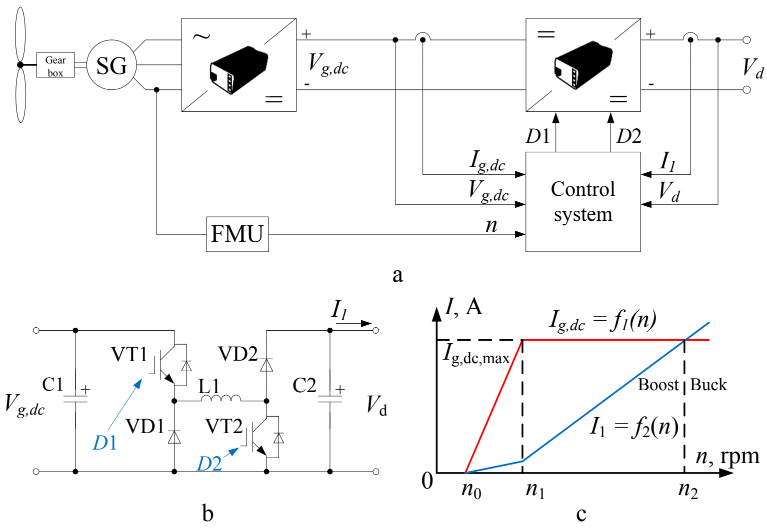


*Fig. 2.* The block diagram of the proposed system (a); the principal scheme (b) of the DC/DC converter and the wind turbine circuit current as a function of generator speed (c): SG – a synchronous generator; FMU – a frequency measurement unit.

Generator current reaches the maximum value $I_{g,dc,max}$ when speed is equal to $n_1$ (Fig. 3); in this case converter current is:

$$I_1^1 = 0.1 \cdot I_{g,dc,\max}, \text{A.} \tag{8}$$

The maximum current of the discussed generator GL-PMG-5000 is $I_{g,dc,max}$ = 10 A. If DC bus rated voltage is 600 V, the speed $n_0$ is equal to 18.5 rpm, but $n_1$ is approximately 65 rpm (Fig. 3). Between $n_0$ and $n_1$ generator, DC voltage is equal to 60 V according to (3). At $n_2$, converter current $I_1$ is equal to $I_{g,dc,max}$, and operation mode of the converter changes to step-down. At $n > n_2$ converter operates in step-down mode.

## 4. THE CONTROL PRINCIPLES OF THE ACTIVE FRONT-END IN THE DC MICROGRID

When $I_{g,dc} = I_{g,dc,max}$ = 10 A and $V_d = V_{d,r}$ = 600 V, generator converter current is equal to:

$$I_1 = \frac{I_{g,dc} \cdot V_{g,dc}}{V_d} = \frac{V_{g,dc}}{60} = \frac{k_{dc} \cdot n - R_g \cdot I_{g,dc}}{60}, \text{A.} \tag{9}$$

At the same time, converter current must be equal to:

$$I_1 = \frac{k_{dc} \cdot n}{60 + \dfrac{R_g \cdot D1}{(1 - D2)}}, \text{A.} \tag{10}$$

The DC microgrid connection to the 3-phase AC grid through the active front-end is studied in the present research [15], [20], so the front-end output current $I_2$ (Fig. 4) is equal to:

$$I_2 = I_{load} - I_1, \text{A}, \tag{11}$$

where $I_{load}$ – load current, A.

If $I_2$ is with "-" sign, the current is transferred into the AC grid. The calculation of the reference current $I_{2,ref}$ of the active rectifier is shown in block diagram (Fig. 3.a). AC grid phase current amplitude is:

$$I_{ph,a} = \frac{2 \cdot I_2}{\sqrt{3}}, \text{A}. \tag{12}$$

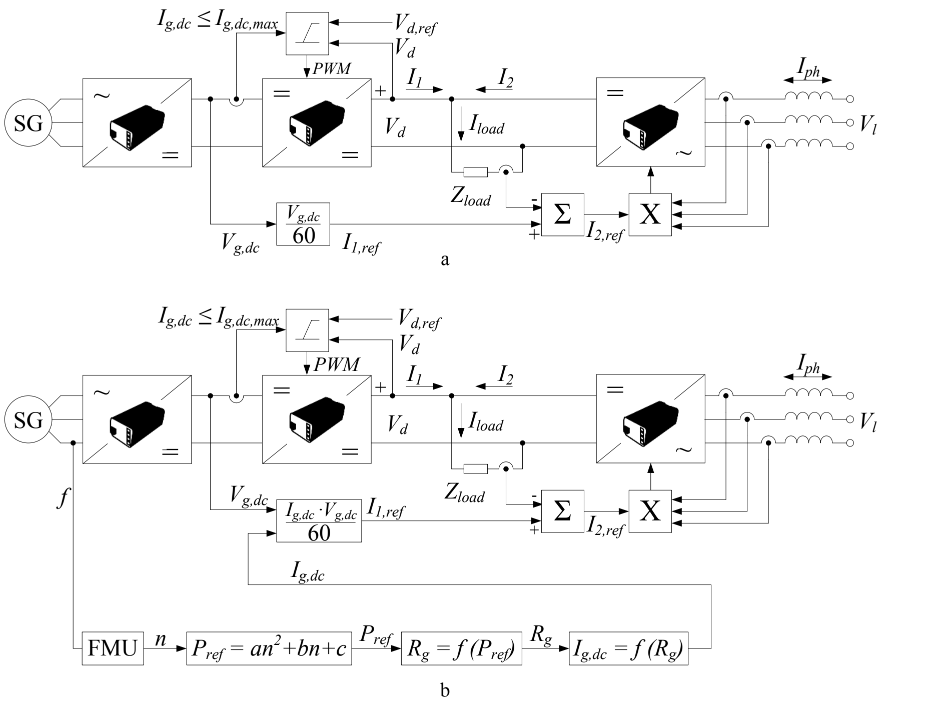


*Fig. 3.* The calculation of the reference current of the active rectifier at generator speed $n > n_l$ (a) and at generator speed $n \le n_l$ (b): $V_{g,dc}$ – wind generator output DC voltage; $V_d$ – DC bus voltage; $V_l$ – AC grid line voltage; $Z_{load}$ – load impedance; $I_{g,dc}$ – wind generator output DC current; $I_1$ – wind generator converter output current; $I_{ph}$ – AC grid phase current; $I_2$ – active rectifier output current; $I_{load}$ – load current.

If generator speed is $n \le n_l$, the calculation of the generator output current $I_{g,dc}$ is needed. For this purpose, the reference power of the generator is calculated [20]. In case of the generator GL-PMG-5000 it is:

$$P_{ref} = 0.0988 \cdot n^2 + 5.3682 \cdot n - 109.02. \quad (13)$$

The current of the generator DC-DC converter is calculated as in (4). The principle of the estimation of the $I_{g,dc}$ and $I_1$ values is presented in Fig. 3.b. According to Fig. 2.c, the mentioned currents were calculated for the generator GL-PMG-5000 (Fig. 4).

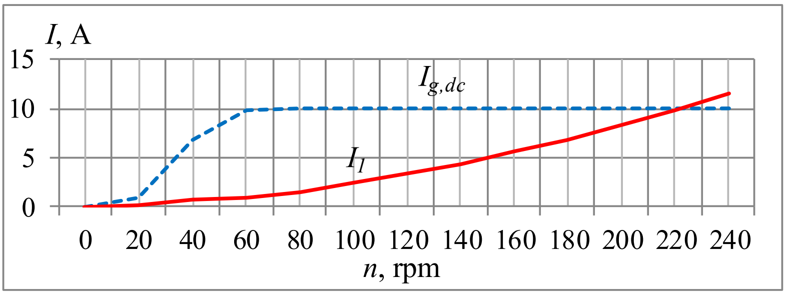


*Fig. 4.* The calculated currents for the circuit of the wind turbine: $I_{g,dc}$ – wind generator output direct current; $I_1$ – wind generator converter output current.

## 5. SIMULATION RESULTS

The proposed control method was confirmed by the PSIM simulation. The current distribution (Fig. 5) is presented at the load resistance 200 Ω and the DC bus rated voltage 600 V. The speed $n_2$ of the discussed PMSG is equal to 222 rpm in the case of generator rated current 10 A.

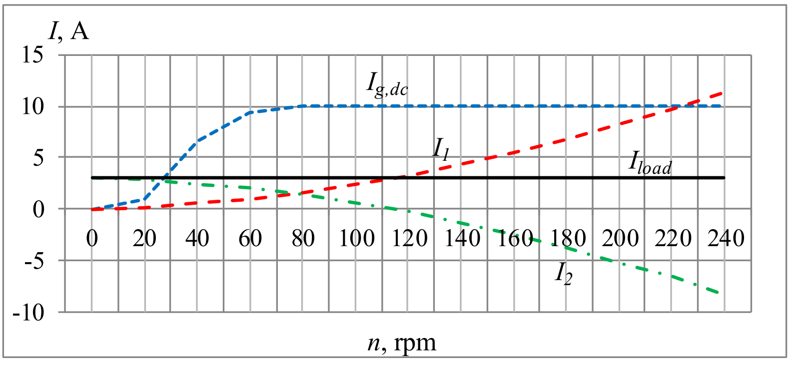


*Fig. 5.* Simulation diagrams of the wind energy based DC microgrid connected to the conventional AC power grid: $I_{g,dc}$ – wind generator output direct current; $I_1$ – wind generator converter output current; $I_2$ – active rectifier current; $I_{load}$ – load current.

The received generator power, conventional grid power and load power are presented in Fig. 6. When $n > 118$ rpm and a load is 200 Ω, the generator starts to transfer produced energy to a conventional power grid; therefore, $I_2$ and $P_{grid}$ values are negative in this speed range.

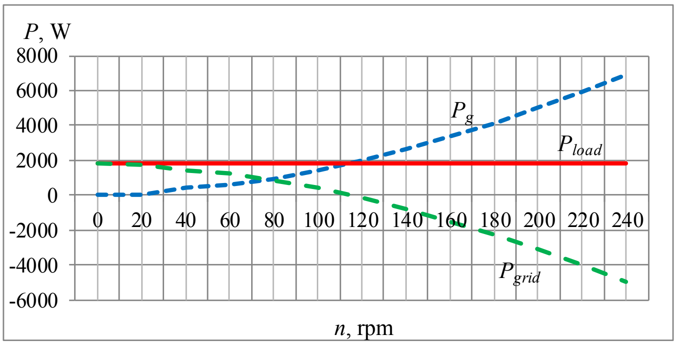


*Fig. 6.* Simulation diagrams of the wind energy based DC microgrid connected to the conventional AC power grid: $P_g$ – wind generator power; $P_{grid}$ – conventional grid power; $P_{load}$ – load power.

In case of DC microgrid connection to the conventional AC grid, the power quality must be taken into account. The simulation presents that the proposed system can provide implementation of this condition. At positive $I_2$ values (the energy is consumed from the AC grid), the AC grid voltage and current are the same phase (Fig. 7).

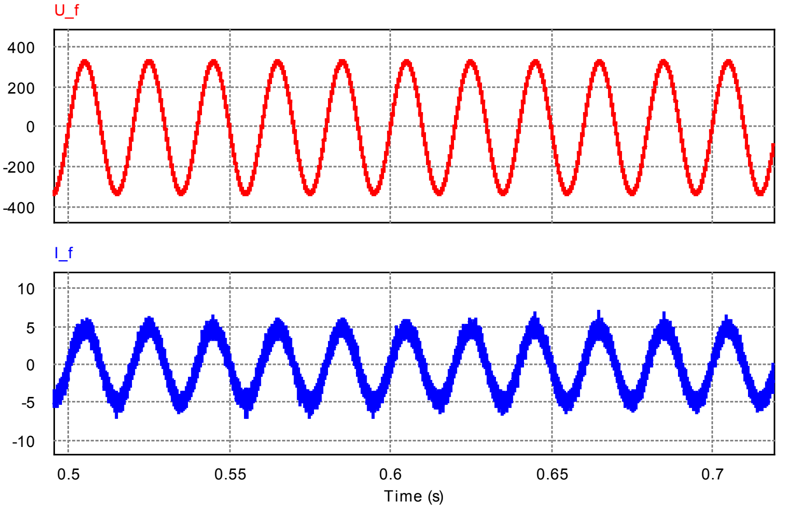


*Fig. 7.* The simulation diagram of the DC microgrid operation with conventional AC grid at generator speed of 200 rpm and load of 50 Ω: U_f – AC grid phase voltage; I_f – AC grid phase current.

## 6. CONCLUSIONS

The DC based microgrid topology is discussed in the present research. Firstly, this choice is determined by the most efficient use of the renewables and the ability to provide uninterrupted power supply. Secondly, the possibility to recuperate the braking energy of the electrical drives and the rest of the generated energy is taken into account. The synchronous generator with full power electronics conversion as a basic energy source of the microgrid has been chosen. In accordance with the national standards and features of the DC bus cooperation with a three-phase power grid, the microgrid rated voltage value of 600 V has been selected, but the allowed minimum voltage has been accepted equal to 565 V.

Synchronous generator interconnection with DC bus is ensured by the use of the buck-boost DC/DC converter, which has been chosen because of the generator technical parameters. The converter control system is based on setting the wind generator optimal current and directly adjusting the DC/DC converter duty cycle. The minimum necessary speed of the discussed generator is 18.5 rpm.

The proposed system is based on the active rectifier, whose control is implemented by determination of the difference between the maximally allowed wind generator DC-DC converter current and load current. This method provides bidirectional energy transmission between DC microgrid and conventional power grid. According to the proposed control principle, the optimum current curve of the discussed permanent magnet synchronous generator has been calculated and recognised by the computer model. The theoretical analysis and computer modelling show the correct operation of the control principles. The proposed method allows using all wind turbine generated energy in a wide range of speeds. Surplus wind energy can be transmitted to the conventional power grid and, if necessary, energy flow from the conventional grid can support the needs of consumers.

## *ACKNOWLEDGEMENTS*

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## UZ VĒJA ENERĢIJAS BALSTĪTA LĪDZSTRĀVAS MIKROTĪKLA VADĪBAS PRINCIPI

G. Zaļeskis, I. Raņķis

Kopsavilkums

Saskaņā ar atjaunojamo enerģijas resursu pielietošanas stratēģiskiem mērķiem, ir svarīgi minimizēt enerģijas patēriņu no centralizētā elektroapgādes tīkla, efektīvi izmantojot atjaunojamos enerģijas resursus un nodrošinot patērētāju stabilo darbību. Pētījuma mērķis ir izveidot tehniskos risinājumus, kas var nodrošināt vēja ģeneratoru efektīvu darbību mazās jaudas līdzstrāvas mikrotīklos, kas nozīme arī vēja enerģijas pārveidošanu pēc iespējas plašākā vēja ģeneratora ātrumu diapazonā.

21.11.2017.