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DFIG based Power Generation System with UPS Function for Variable Speed Applications

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***Abstract*—The power generation system with DFIG, which can be used as an autonomous power system after the loss of mains in distributed generation network, is described. After the mains outage, a fixed frequency and amplitude of the output voltage is obtained, despite of the variable rotor speed. For this reason it can be successfully applied in the variable speed wind turbines, adjustable speed water plants or diesel engines. Moreover, the stand alone operation of DFIG is useful in a flywheel based high energy rotary UPS. Output voltage is controlled directly, by the synchronization of actual voltage vector with the reference vector represented in a synchronously rotating polar frame. The rotor current angular speed is obtained as a result of vectorial phase locked loop operation. Any sensors or estimators of the rotor speed or position are unnecessary. Both – amplitude and angle control loops are linear. The use of standalone operation in a grid connected systems requires mains outage detection. Also the grid voltage recovery requires a method of synchronization and soft connection of generator to the grid. The proposed methods of output voltage control, synchronization and detection of mains loss were tested in a laboratory system.**

***Index Terms*—power generation, power generation faults, uninterruptible power systems.**

I. Introduction

CONCEPT of distributed generation system DGS assumes, that the power network is supplied not only from the central power stations, but also from many different local power systems (e.g. wind turbines, water plants, fuel cells, photovoltaic panels, diesel engines, gas turbines, etc.) [1]. Part of the additional power sources is connected close to the supplied load, therefore they can supply part of an isolated load during the loss of mains, caused by e.g. breaking of the transmission line or permanent short circuit in the grid. This requires the local power sources to be prepared for standalone operation [2]. DGS require intelligent control of the energy sources and fast reaction to the grid disturbances like over- and undervoltage, overloads, short circuit, line breaking [3], etc. Modern renewable energy sources equipped with power electronics can support the grid in the range of voltage quality improvement and filtering of the grid current harmonics.

Uninterrupted supply is very important to the part of load connected to the grid. If necessary, the local power sources should change their operation mode without rapid change of the output voltage phase. Therefore, to achieve controlled soft change of the operation mode, from grid connected to standalone, the control system has to be equipped with algorithms of the mains outage detection. After grid voltage recovery, the local power system can be softly connected to the grid after prior synchronization of the grid and stator voltage.

The power generation based on the variable speed wind turbines or adjustable speed water plants, are popular in a distributed generation network. The typical operation mode is the grid connected, as in this case, the produced power can be adjusted to the maximum efficiency. It is clear, that the power delivered from the wind turbine may be to low to supply the load during autonomous operation. In such case, the supply system should be supported by additional power source e.g. diesel engine [4] or energy storages. Despite of the above, standalone operation of the variable speed generators is possible and can be used for uninterruptible load supply.

This paper presents a method of output voltage control of the doubly fed induction generator DFIG during standalone variable speed operation. The proposed method uses vectorial phase locked loop PLL [5] for synchronization of the actual output voltage vector with the reference vector. Amplitude of the output voltage is proportional to the rotor current amplitude, therefore the control loop of voltage amplitude is very simple. Positive and negative sequence components are used for the voltage asymmetry correction during unbalanced load supply. Four wire system is needed on the stator side for an unbalanced load supply.

The used PLL structure allows to control the output frequency, as well as the stator voltage phase, which can be easily synchronized with the grid voltage and softly connected to the network. Methods of power control for grid connected DFIG are described widely [6]–[9], therefore will not be discussed in this paper. One of the power control method, used to present the controlled disconnection from the network after the loss of mains, is similar to the one presented in [9]. The controlled disconnection is obtained by mains outage detection methods, which base on monitoring of the amplitude and frequency of the stator voltage.

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II. Standalone Power Generation with DFIG

A. Topology of standalone DFIG

The power electronics used in slip ring generator system consists of rotor connected to the power converter PCo1, and front-end power converter PCo2 (Fig. 1). In both modes – standalone and grid connected - the main role of front-end converter PCo2 is to maintain fixed level of the DC link voltage. In grid connected systems, the power factor correction PFC control of PCo2 is generally applied. In case of autonomous operation, an additional function of PCo2, as the reactive power compensator or active filter, can be very useful. Standalone system is equipped with capacitances C_f to reduce the high frequency distortions produced by power converters switching. The stator of the machine is not connected to grid, but supplies the isolated load. As opposed to other solutions [10][11] of standalone DFIG, no additional inductances connected neither to the rotor nor to the stator are needed, what makes the power system lighter and less expensive. For the operation within subsynchronous range of speed, the front-end power electronics converter PCo2 can be replaced with a simple three phase diode bridge.

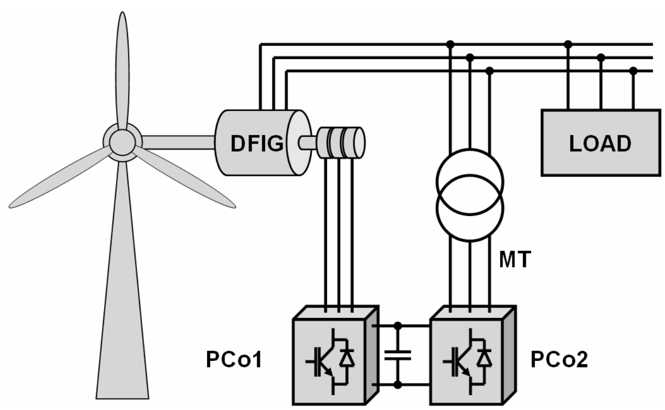

Fig. 1. Standalone power generation system with slip-ring induction generator.

Four wire system on the stator side has to be used for unbalanced load supply. Nevertheless, the power electronics converter can still operate in the three wire system, as it is isolated by DFIG and matching transformer MT from the four wire stator side. The zero sequence component on the stator side is referred to neutral point of the star connected rotor. However from the load point of view there is no zero sequence in the output voltage, as this voltage is related to the neutral point of the stator. This situation is similar to the one where transformer supplies the low voltage loads in electrical distribution network. The three wire system on the primary side is enough to obtain symmetrical voltage on secondary side even during full asymmetry of the load, caused e.g. by line breaking in single phase on the secondary side. The only problem, is to select the type of connection on the primary windings, taking into consideration, the zero sequence flux flows on the rotor side through the encapsulation (star connection) or in the delta closed loop (delta connection).

Small voltage unbalance caused by different voltage drops on the winding resistance and leakage inductance in each phase, can be successfully compensated by negative sequence current fed to the rotor.

In case of significant load unbalance, the method of voltage asymmetry correction is required. Additional part of control responsible for correction of the voltage asymmetry, is based on the negative sequence components of the output voltage vector. The method presented in [12] uses the speed sensor to obtain the transformation angle, whereas it is possible without information about the rotor speed or position using PLL structure.

B. Single Phase Equivalent Diagram of Standalone DFIG

Single phase equivalent electrical diagram is presented in Fig. 2a. The PWM converter connected to the rotor draws the power from stator by front-end PCo2 converter. The PCo2 is current controlled, so it can be treated as an additional load, of power which is fractional in relation to the generator rated power. Therefore, in range of synthesis of the rotor converter control system, the standalone DFIG can be treated as a generator with a rotor supplied from independent source (Fig. 2b). New load R'_{ld} consist of load supplied from the system R_{ld} and additional load, which represents the front-end converter.

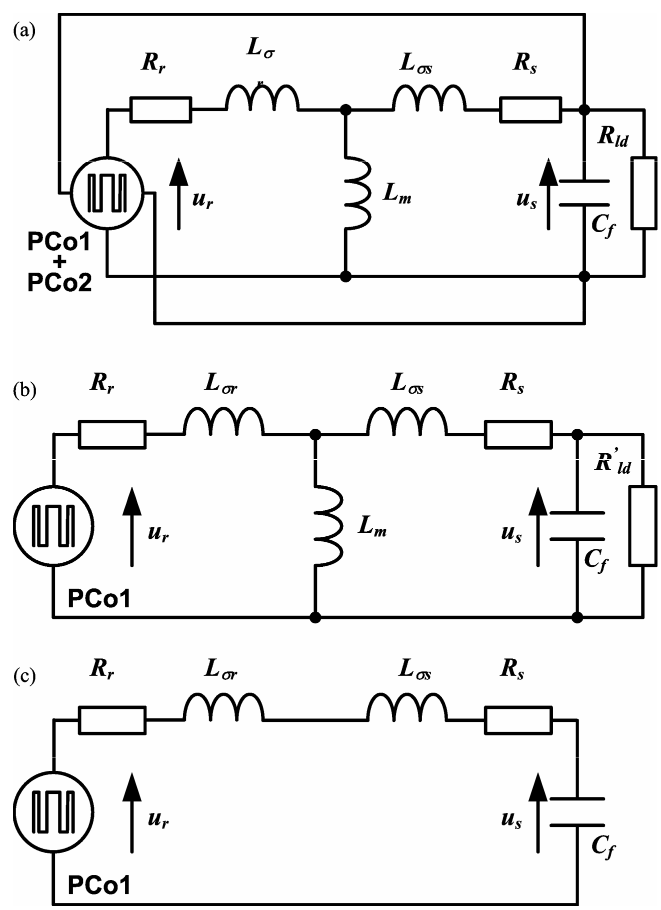

Fig. 2. Single phase diagrams of standalone DFIG, a) power electronic between the rotor and stator, b) equivalent load R_{ld}' representing supplied load R_{ld} and active power of front-end converter, c) diagram of LC output filter

A current controlled rotor converter PCo1 in simplification can be treated as a current source. This can be useful for preliminary simulation tests, in which the relation between rotor current and stator voltage can be evaluated. However, from the PWM rotor voltage point of view, the model includes a low pass filter, which should be prototyped appropriately, in order to achieve high stability and high quality of the produced voltage. For open loop operation, the voltage stability is the worst during no load operation, due to the smallest damping ratio. Therefore the prototyping of output filtering capacitors should be made, using the model of unloaded machine.

C. *Selection of the Low Pass Filter Capacitor*

Lets assume, that the magnetizing inductance represents the ideal transformer. This inductance does not participate in a PWM voltage filtering, therefore the model of the output filter is simplified to the rotor and stator leakage inductance and filtering capacitance (Fig. 2c). For given speed and load, the model can be treated as a stationary. Rotor winding resistance R_r and rotor leakage inductance $L_{\sigma r}$ are referred to the stator.

The main criteria for the capacitor selection is to achieve a resonant frequency of the filter approximately in the middle (on logarithmic scale) between operational frequency (50Hz) and power electronics switching frequency. Otherwise the system may be unstable, especially during no load operation, as a resonance may occur.

From the load point of view, the value of filtering capacitor should be as big as possible, what gives smaller voltage distortions produced by nonlinear load. However, in a rotating machine there are some limitations to the volume of capacitors connected to the stator. The reactive power of capacitors, has to be lower than the magnetizing power, because during overcompensation, the remanence flux generates voltage on the stator. This is advisable feature for self-excited cage induction generator. However in the DFIG, flux originated from remanence, rotates with mechanical speed, while the flux originated from rotor currents rotates synchronously. These two fluxes cannot be synchronized together, so the induced stator voltage is unstable.

For the medium power machine of 250kW 220/380V and cosϕ=0.91, the mutual inductance L_m, which is mainly responsible for reactive power, is equal to 4.06mH. The total leakage inductance $\Sigma(L_{\sigma r},L_{\sigma s})$ is equal to 0.12mH. Basing on the second criteria of the capacitor selection, the value of capacitance is limited to 2.5mF for operating frequency of 50Hz. To obtain a resonance frequency of the LC output filter at 400Hz, system has to be equipped with 1.32mF of stator connected capacitor. This is near 50% less than liming value, and enough to obtain voltage stability during no load operation. Capacitors connected to the stator may be increased for significantly loaded DFIG, due to the higher dumping ratio and better stability of the system.

III. Direct Voltage Control Method of DFIG

A. *Assumptions for Control of the Standalone DFIG*

During standalone operation, the frequency and amplitude of the output voltage must be controlled and should be fixed, despite the variable rotor speed. To achieve satisfactory dynamics of the system, the inner control loop of the rotor current should be applied. Obtaining the rotor current frequency without the use of neither speed or position measurements, will be a significant achievement. One of the requirements of universal generation system is to have a possibility to supply an unbalanced load. The standalone DFIG presented in publications uses the rotor speed sensors [13] or position encoders [10][14]. In [11], the rotor current frequency is obtained by the use of speed observer, however the system requires a very large (30mH/phase) additional inductance connected with the rotor in series, to filter the rotor current distortions of PWM frequency. Moreover, the system was tested only with symmetrical resistive load, what is a significant simplification for standalone system supplying the isolated load. The correct operation of speed observer for nonlinear load has not been proven. In such case, the rotor and stator currents are strongly distorted.

B. *Control of Output Amplitude and Frequency*

For given speed and load, the amplitude of the output voltage in standalone operated DFIG is proportional to the amplitude of rotor current. This is justified by the models presented in Fig. 3b. The controller of the output voltage amplitude is easy to implement, basing on the voltage vectors in stationary αβ or rotating synchronously dq frames. The amplitude of output voltage vector is easy to calculate:

$$|u_s| = \sqrt{u_{s\alpha}^2 + u_{s\beta}^2} = \sqrt{u_{sd}^2 + u_{sq}^2} \tag{1}$$

The reference and actual amplitude of the output voltage vectors are fixed in steady state; therefore PI controllers are used to control them. Tuning of the controller is very easy, as the model of standalone DFIG in the steady state is simple.

The reference fixed frequency of the output voltage can be obtained by fixed angle α_{us} between the stator voltage vector $\boldsymbol{u_s}$ and the d axis of the rotating $dq_{(p)}$ frame. The $dq_{(p)}$ frame rotates with synchronous speed Ω_s in positive direction. Reference angle α_{us}* is equal to zero, what means that the reference stator voltage vector overlaps with the d axis. Output signal from the Rα controller responds to the reference signal of the rotor current angular speed Ω_{ir}*, which is integrated to achieve reference angle of the rotor current vector ϕ^*_{ir}. The displacement of the actual stator voltage vector $\boldsymbol{u_s}$ from the reference position $\boldsymbol{u_s}$* by angle α_{us} (Fig. 3) implicates, that the reference angular speed Ω_{ir}* of the rotor current vector $\boldsymbol{i_r}$ is either increased or decreased by the Rα controller, depending on the α_{us} sign.

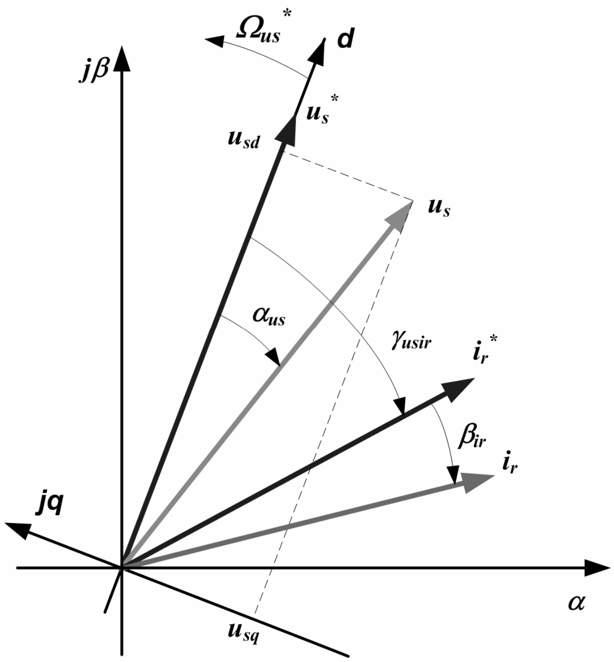

Fig. 3. Stator voltage $\boldsymbol{u}_s$ and rotor current $\boldsymbol{i}_r$ vectors in transient states

The control of the output frequency consists of synchronization of the actual voltage vector $\boldsymbol{u}_s$ with reference $\boldsymbol{u}_s$*. This can be obtained by the change of the rotor current frequency (it looks like a vectorial PLL structure [5], but with angular speed instead of the angle as the output signal).

Transformation of the rotor current vector, from polar coordinates $A\phi_{(r)}$ to three phase system $abc_{(r)}$ connected with rotor, generates reference signals for the rotor currents i_{ra}*, i_{rb}*, i_{rc}*. The method is called Direct Voltage Control DVC [15][16] of the standalone DFIG and is shown in Fig. 4b.

Time constant of the speed variation is much higher than the electrical constant of the machine, therefore there is no need for a very fast controller Rα of the stator voltage angle.

Time constant of the RU controller of the stator voltage amplitude has to be adequate to the time constant of the machine model. Controllers tuning was realized by the step-response research and was not analytically analyzed using the mathematical model of the machine. The goal is to present the effectiveness of the control method, however the future work will have to cover the analysis of controller tuning.

It should be clearly stated, that during motor operation of DFIG, the measuring or estimation of rotor speed or position is mandatory. However, during variable speed power generation with DFIG, the most important issue is to obtain high quality either of the power delivered to grid or of stator voltage, depending on the operation mode. It can be obtained by correct determination of the rotor current frequency and phase. Used PLL structure for synchronization of the actual voltage with reference vector for standalone operation, causes the mechanical variables are needless. Sensorless control does not means, that the control is made without any measurements. The stator voltage and rotor current measurements are needed to control the rotor converter.

The control of the front-end converter and voltage asymmetry correction does not influence on the grid connection processes, therefore will not be described widely in this paper. Detailed description of extended direct voltage control EDVC, including the voltage asymmetry correction can be found in [17][18]. The example of control methods of typical front-end converter are described in [19][20].

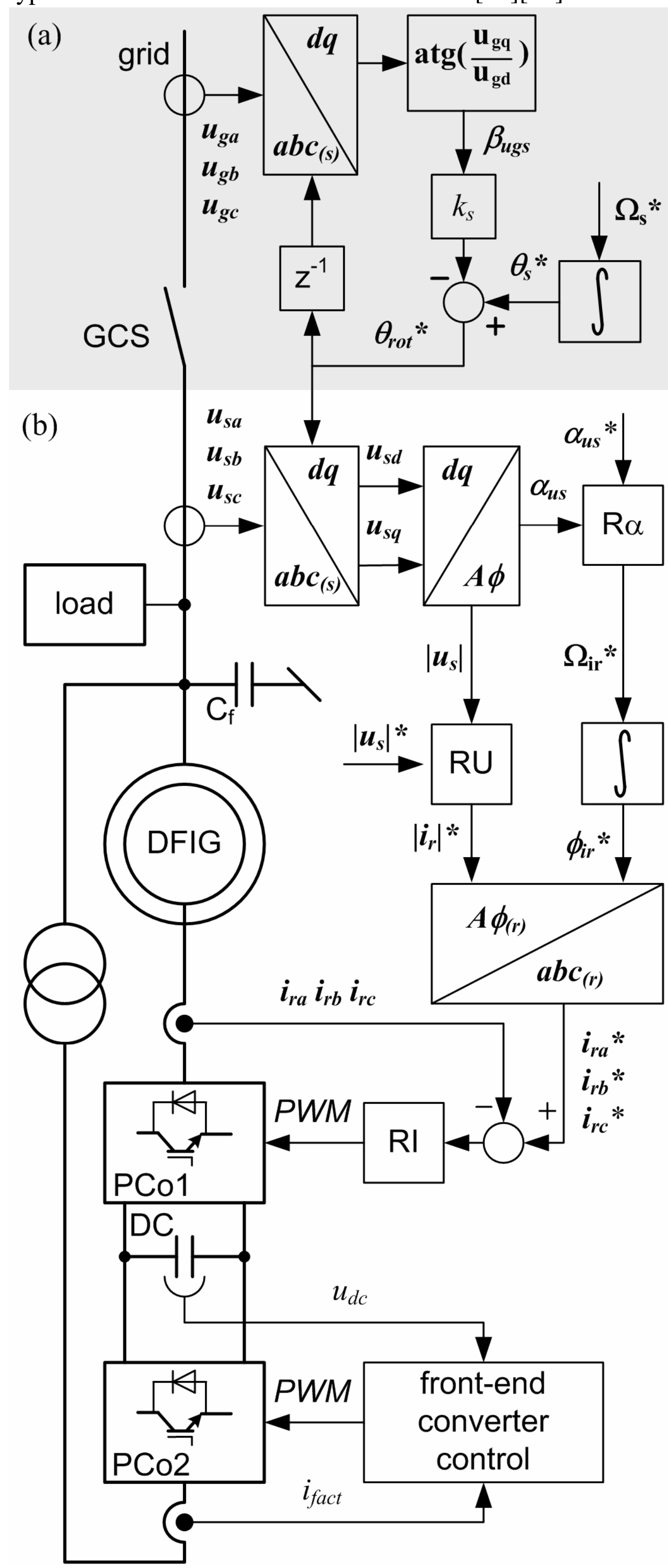

Fig. 4. Sensorless Direct Voltage Control (b) with synchronization block (a).

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IV. Grid Connection and Disconnection Transients

A. Applications

Standalone operation can be used in distributed power systems. After the loss of mains, the local power source can take over the supply of the load. It is useful for wind turbine, water plants, solar panels, diesel engines, gas turbines etc. The variable speed generator, which is designed for both – grid connected and standalone operation – should be equipped with grid connection switch GCS, which allows for controlled grid connection and disconnection (Fig. 5).

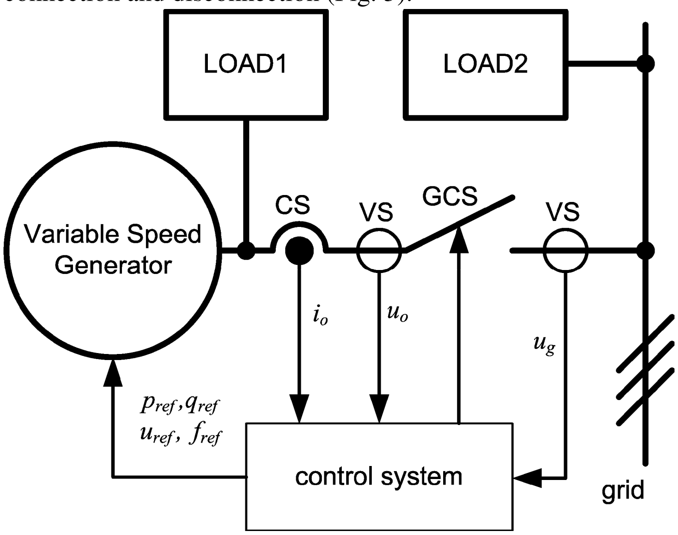

Fig. 5. Universal grid connected and/or standalone power generation system.

The power of local source is limited, therefore it can supply only a part of the grid load. The generator and selected load is isolated from the grid only by the GSC switch. In order to achieve uninterruptible supply of the selected load, the method of mains outage detection should be applied [21]. The second role of GSC switch is to protect the load from the rapid change of supply voltage phase. In case of grid voltage recovery, the generator is reconnected to the grid after the earlier voltage synchronization [22]. Synchronization of the generator with grid requires sensors of grid and output voltages. The GCS is opened or closed depending on the operation mode and selected control (voltage or power).

Apart from renewable sources, the variable speed generators can be used in a rotary UPS systems. The difference in relation to e.g. wind turbine is, that the UPS system consume the power during grid connection mode to maintain the speed on the reference level. In steady state operates as a motor with minimum power consumption – ("standby" operation). After the grid fault detection, the application of standalone control is identical to wind turbine. Once the grid voltage recovers, the UPS system is synchronized and again operates as a motor to store the energy in a flywheel. Sometimes, the flywheel is coupled with diesel engine on the same shaft, what allows for the sustained operation in standalone mode during permanent grid fault. The flywheel delivers the energy until the diesel engine starts.

B. Synchronization and Soft Connection to Grid.

Apart from amplitude and frequency, the phase of the output voltage is also controlled, using DVC method. This makes the voltage vector easy to synchronize with the grid. Voltage synchronization is obtained by elimination of the angle β_{ugs} between the vectors of grid voltage $\boldsymbol{u_g}$ and stator voltage $\boldsymbol{u_s}$. The β_{ugs} angle, obtained using a cross product of the vectors, can be used for voltage synchronization [23]. The sinus function of this angle is equal to zero when the vectors are parallel, what means that the voltages are synchronized and the stand alone generator is ready for grid connection. Second way to get the angle β_{ugs} between vectors of voltages is shown in Fig. 4a. The angle β_{ugs}, between stator voltage vector $\boldsymbol{u_s}$, and grid voltage vector $\boldsymbol{u_g}$, is reduced by slow iterative turning of the rotating synchronously dq frame in the direction of the grid voltage vector $\boldsymbol{u_g}$, what is presented in Fig. 6.

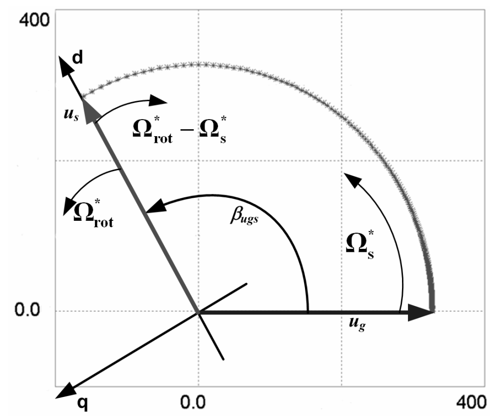

Fig. 6. Synchronization of the grid $\boldsymbol{u_g}$ and stator $\boldsymbol{u_s}$ voltage vectors.

Two vectorial PLL structures operate simultaneously. During synchronization, the reference dq frame connected with the stator voltage rotates with angular speed

$$\Omega^*_{\text{rot}} = \Omega^*_{\text{s}} - k_s \frac{d\beta_{ugs}}{dt} \tag{5}$$

or it can be described as an angle of dq frame rotation

$$\theta^*_{rot}(t) = \int \Omega^*_{\text{s}} d\tau - k_s \beta_{ugs} = \theta^*_s(t) - k_s \beta_{ugs} \tag{6}$$

while the grid voltage vector $\boldsymbol{u_g}$ rotates synchronously with speed Ω_s^*. The k_s factor is responsible for the synchronization speed. The β_{ugs} is iteratively decreased, therefore the dq frame is synchronized with grid voltage $\boldsymbol{u_g}$, whereas the stator voltage $\boldsymbol{u_s}$ is synchronized with the rotating dq frame. This results in, stator $\boldsymbol{u_s}$ and grid $\boldsymbol{u_g}$ voltage synchronization. If the angle β_{ugs} is close to zero, the GCS switch can be closed and generator can be connected to the grid, what requires the control method to be changed to active and reactive power control.

C. Methods of the Mains Outage Detection and Controllable Disconnection from Power Network

During the grid connection mode, active and reactive power controllers are used. These controllers cannot guarantee fixed amplitude and frequency of the generated voltage after the loss of mains. Change of the control method causes, that the mains outage detection is necessary. The soft transient from grid connection to stand alone mode protects the load from the rapid change of the supply voltage phase.

As the amplitude and frequency of the stator voltage, controlled by power controllers, are not stable during the system stand alone operation, these two variables are used for the mains outage detection.

Failure of the transmission line (e.g. breaking) causes, that the total load connected between the DFIG and breaking point is instantly supplied from the generator. The load power, higher than the power delivered to grid causes the voltage amplitude to decrease. Quite the opposite, if the load power is lower than the delivered power, it causes that the voltage amplitude to increase. In both cases, comparison of measured amplitude with the rated range of voltage, gives the information about the loss of main. The comparison of the voltage vector amplitude can be placed in every step of computation.

If the power of load supplied from the generator after the line breaking is approximately equal to the power delivered to the grid, the voltage vector amplitude may still be within the rated range and the mains outage may be not detected. Therefore the second method based on the frequency of the voltage is applied to detect grid voltage faults. The frequency of stator voltage u_s is determined by two neighboring angular positions calculated in αβ coordinates every 5ms. During this period, the grid voltage vector $\boldsymbol{u_g}$ should describe the angle equal to π/2 for 50Hz frequency. The calculated angle significantly higher or lower than π/2 indicates the change of the output frequency, caused by line braking, and engages island operation by power controllers. More frequent calculation (e.g. in every 1ms) of angular position causes the frequency determination to be noise sensitive.

The first method based on the voltage vector amplitude is much faster than the second one, based on the frequency, due to immediate change of the amplitude value. However, this method is insufficient, and should be complemented by the second one. The mains outage is caused not only by line breaking but also by other grid disturbances e.g. grid short-circuit or overload. The grid short-circuit results in failure of the grid voltage and value much lower, than the rated one. Therefore the mains outage caused by grid short circuit can be easily detected by comparison of the stator voltage amplitude with rated value.

In the case of rotary UPS system, where during grid connected operation the power is drawn from grid, the first method is sufficient to detect loss of mains, because the voltage falls rapidly to zero and UPS system is ready for standalone operation immediately.

V. EXPERIMANTAL RESULTS

Proposed methods of DFIG output voltage control, synchronization and detection of mains outage were verified in a laboratory system. Parameters of the power generation system are presented in Table I.

TABLE I
PARAMETERS OF THE POWER GENERATION SYSTEM

rated Power	2.2kW
rated speed n	950rpm
rated U_s	220/380V (D/Y)
rated I_s	9.8/5.7A (D/Y)
rated U_r	108V
rated I_r	13A
cos ϕ	0.71
L_m	212mH
$\Sigma(L_{\sigma r}, L_{\sigma s})$	8mH
R_s	1.7Ω
R_r	2.5Ω
C_f	21uF
Switching f	8kHz
Sampling f	16kHz

DC motor was used as a variable speed primary drive. The control methods were implemented in C language and executed in DSP controller build on ADSP-21061 with FPGA support. The detailed description of floating point integrated DSP/FPGA controller, prototyping of control method and simulation in PSIM software can be found in [23]. Filtering capacitor is 21uF and the equivalent leakage inductance $L_{\sigma rs}$ is equal to 8mH, what provides the resonant frequency of filter close to 0.4kHz. At the same time, the generator is not overcompensated, and output voltage is stable.

The output voltage of standalone DFIG obtained by DVC method is presented in Fig. 7b. The speed change crosses the synchronous value twice, what is indicated by the rotor current shape (Fig. 7a). Fig 7b is registered in time window marked in Fig. 7a. High quality of the stator voltage is obtained in spite of the nonlinear load. The power of nonlinear load is equal to 50% of the generator rated power.

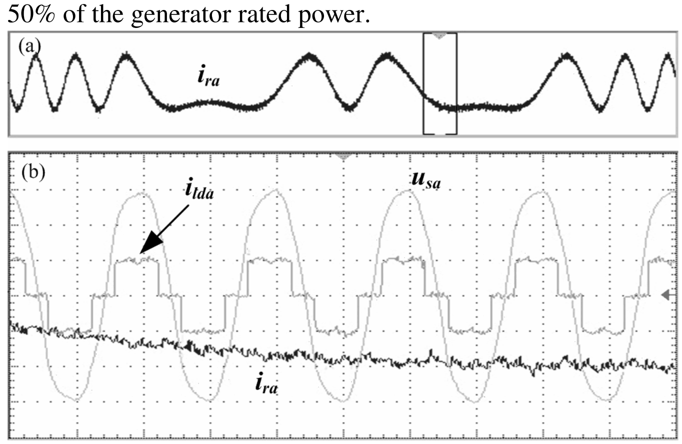

Fig. 7. Oscillogram presenting a) rotor current i_{ra}, b) rotor current i_{ra}, stator voltage u_{sa}, load current i_{lda}, during variable speed operation of DFIG.

Fig. 8 presents the step loading of the generator, by nonlinear load of half the rated power. The transient is quite short (3 periods of the generated voltage and overvoltage does not exceed 10%). The bigger damping ratio of loaded generator, shortens the transient time during step loading (close to one period of the generated voltage) [16][17].

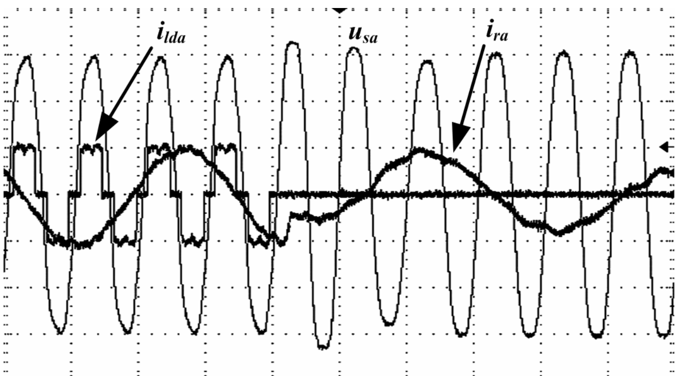

Fig. 8. Oscillogram presenting stator voltage u_{sa} (100V/div), load current i_{ra} (2A/div), rotor current i_{ra} (20A/div).

Fig. 9a presents oscillogram of synchronization of the voltage after grid recovery. Fig. 9b presents final part of synchronization and soft connection to the grid in t_{con} instant. Depending on k_s factor (5)(6) the synchronization process can be dynamic or slow. Fast synchronization (0.1s and above) may be applied in unloaded generator only for soft connection to grid, to eliminate the impact of the magnetizing current. Slow synchronization (e.g. 10 sec.) should be applied in generators supplying an isolated load, to protect the load from the rapid change of the voltage phase, during grid connection process. The proposed synchronization method allows for connection of the generator during operation at synchronous, sub-synchronous and super-synchronous speed, while authors of [24] propose the synchronization only with synchronous speed, and change of the voltage phase like in synchronous machines - by the change of mechanical angle. Therefore, the significant advantage of DFIG (decoupling between rotor speed and stator frequency) is not taken into account in this proposed synchronization method.

Fig. 10a, 10b presents the controlled disconnection from the grid. Between fault instant t_f and disconnection instant t_{off}, the grid is supplied by the DFIG, therefore grid voltage u_{ga} is indicated. Increase of the voltage amplitude (Fig. 10a) and deviation of output frequency (Fig 10b) indicates grid fault. Then the grid connection switch GCS is opened and only selected load is supplied from the DFIG. The remaining part of grid is separated to protect the DFIG from overload. The method based on the amplitude determination is immediate, however in the laboratory setup used an electromechanical switch. The use of thyristor switch will allow the generator to operate without delay. The second method based on frequency monitoring requires a small number of periods of generated voltage, as the frequency deviation proceeds much slower than amplitude change.

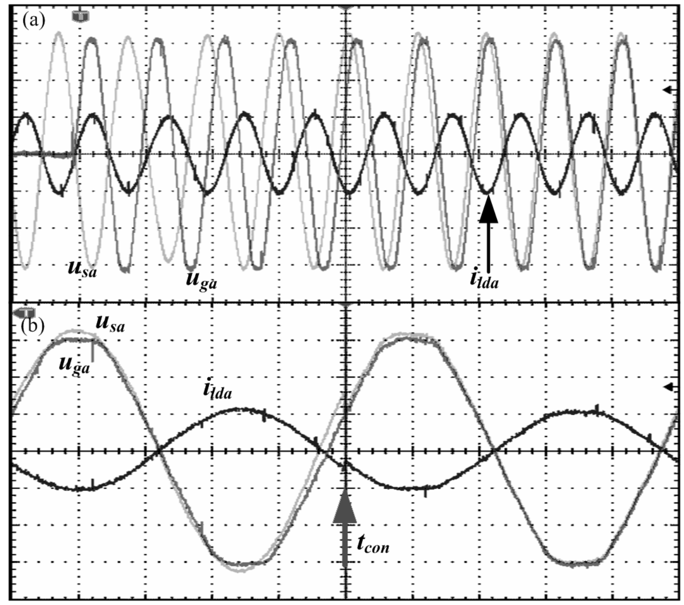

Fig. 9. Oscillogram presenting stator and grid voltages u_{sa}, u_{ga} (100V/div), load current i_{lda} (2A/div) during synchronization (a) and grid connection (b)

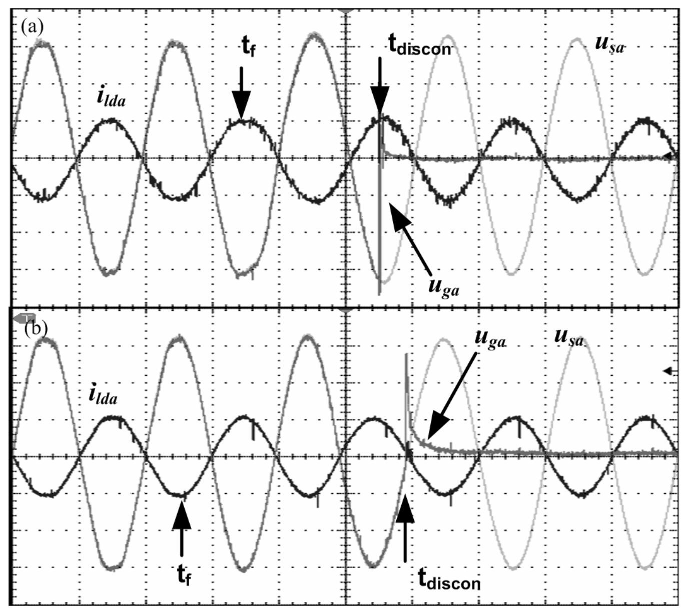

Fig. 10. Oscillogram presenting stator and grid voltages u_{sa}, u_{ga} (100V/div), load current i_{lda} (2A/div) during controlled disconnection from power grid based on amplitude measurement (a) and frequency monitoring (b).

VI. Conclusion

Variable speed system with doubly fed induction generator allow for standalone operation with controlled frequency and amplitude of the generated voltage. The Direct Voltage Control method does not use any measured or estimated signal of the rotor speed or position. Controlled phase of the stator voltage allows the generator to be easily synchronized with the grid and softly connected. The mains outage detection methods based on the amplitude and frequency monitoring are sufficient for variable speed DFIG controlled disconnection and change of operation mode from grid connected to stand-alone.

The methods of output voltage control, detection of loss of mains and synchronization with the grid permits the uninterruptible supply of the selected load connected to the grid. The proposed methods were tested in laboratory system and correctness of algorithms was confirmed.

VII. Future Work

Future work will concern the laboratory tests of rotary UPS and the selection of the speed sensorless control method for motor operation of DFM. Mathematical analysis of controller tuning will be done. Two independently controlled standalone slip-ring induction generators for supply of the same load are also an object of authors interests.

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