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Automatic control of the synchronous generator converter with permanent magnets of a wind turbine

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Abstract. The work presents a method of automatic control of the frequency converter of the wind turbine generator so that it operates in the maximum power zone charged at a continuous and rapid wind speed variation to which is added as a disruptive element and the mechanical inertia of the turbine. The method is based on the control and knowledge of the current value in the intermediate circuit of the converter.
Keywords: TV – wind turbine, GSMP – synchronous generator with permanent magnets, MPP maximum power point, VUM – momentary angular speed

1.Introduction

The method of bringing to the MPP area, by modifying the load properly to the electric generator, requires the measurement of wind speed and is quite performance,[17,19,21], in certain conditions. These conditions can be analyzed by knowing the variations in wind speed over time and taking into account the values of the moments of inertia.

There are geographical areas where wind speed changes its value a little over time,[8,9,17]. In Romania the wind speed varies pronounced over time and for this reason the method can be applicable,in certain areas only after a prior study.

The method is based on the dependence of the TV power of VUM, that is, the fact that the function $P_{TV}(\omega)$ at a certain speed, shows a maximum at the value ω_{OPTIM}, for VUM, Figure 1.

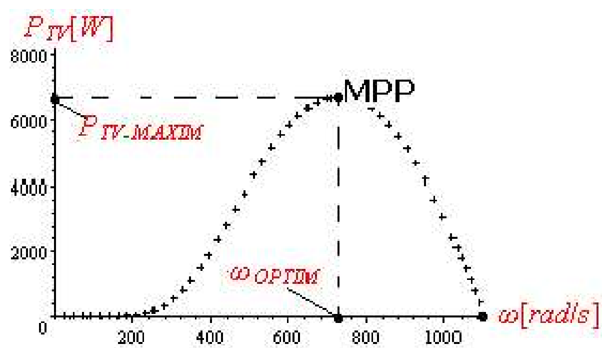

Figure 1. The power feature on TV..

At wind speeds that do not change its value over time, operation in the MPP area can be done relatively easily. At significantly variable wind speeds over time the problem becomes complex and sometimes impossible to solve in cases where the wind changes rapidly over time the value. The analysis of the function in the MPP area is done by simulation using mathematical models specific to TV and GSMP. By modifying the load at the GSMP it tends towards the MPP area and the transient phenomenon is visualized by solving the equation movements to the system TV_GSMP.The simulations presented in the paper are based on the classical mathematical models of TV and GSMP, taken from [14] and on their basis are deducted optimal VUM, _OPTIM.

2. EXPERIMENT DESCRIPTION

The simulations are based on the equation of movement:

$$J\frac{d\omega}{dt} = M_{TV} - M_{GSMP}$$

where: J - the moment of equivalent inertia; M_{TV} - the moment on TV; M_{GSMP} - moment at GSMP

By imposing the angle of conduction to the interposed converters between the GSMP and the network, various values are realized for load resistance and, therefore, for the current. I_{CC}. The scheme of the management system is shown in Figure 2

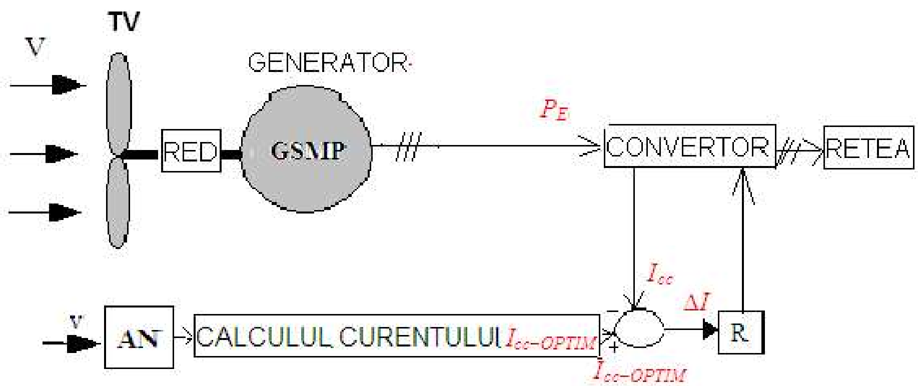

Figure 2. The scheme of the control system TV

Bringing the system into the optimal energy zone is done by imposing a current in the intermediate circuit of the converter I_{CC} ,result of the energy balance,as shown in the following.

To achieve VUM: ω_{OPTIM} it is necessary to change the load value at GSMP. This load change should be calculated on the basis of:

-variations in the kinetic energies of the rotating masses;

-optimal VUM value to be achieved at the given time.

From the equation of motion: $J\frac{d\omega}{dt} = M_{TV} - M_{GSMP}$

by multiplying by ω is obtained: $J\frac{d\omega}{dt}\omega = \omega M_{TV} - \omega M_{GSMP}$ or by integration, on the sampling range $\Delta t = t_k - t_{k-1}$, results:

$$\frac{J}{2}(\omega_k^2 - \omega_{k-1}^2) = \int_{t_{k-1}}^{t_k} P_{TV}\,dt - \int_{t_{k-1}}^{t_k} P_{GSMP}\,dt$$

where to get the energy to be taken over, on the Δt interval, by the GSMP:

$$W_{GSMP} = \int_{t_{k-1}}^{t_k} P_{GSMP}\,dt = \int_{t_{k-1}}^{t_k} P_{TV}\,dt - \frac{J}{2}(\omega_k^2 - \omega_{k-1}^2) = E(\Delta t) - \frac{J}{2}(\omega_k^2 - \omega_{k-1}^2)$$

where: $E(\Delta t) -$ the energy captured, on the Δt range, by the TV.

The energy taken over, on the range $\Delta t = t_k - t_{k-1}$, by GSMP, has two components:

1) $-\int_{t_{k-1}}^{t_k} P_{TV}\,dt$-energy captured by TV;

2) $-\frac{J}{2}(\omega_k^2 - \omega_{k-1}^2)$- kinetic energy of rotation.

The driving process consists of two stages:
1) stage I - bringing the system to the energy-optimal zone;
2) stage II - maintaining the system in the energy-optimal zone;

Stage I - bringing the system to the energy-optimal zone
Bringing the system into the maximum energy zone can be done in two ways:
1) by charging the generator at maximum power if the initial VUM, corresponding the moment of coupling, is greater than ω_{OPTIM} or,
2) GSMP coupling to $\omega = \omega_{OPTIM}$,to empty system operation if initial VUM ,the anterior coupling is smaller than ω_{OPTIM}.

Stage II-maintenance of the system in the optimal area
The energy taken over by GSMP , W_{GSMP},in the time interval: $\Delta t = 40 - 75[s]$,can be estimated by metering of electricity over that time frame or, in simulations, by solving the equation of movement and using the fact that power is derived from energy, as follows:

$$P_{G-arbore} = \frac{dW_G}{dt}$$

By solving the equation of movement, you can visualize the process in the time interval:
$\Delta t = 40 - 75[s]$. At $t = 70[s]$ VUM reaches the value ω compared to value optimal: $\omega > \omega_{OPTIM}$
In the same time interval the variation of kinetic energy has the value:

$$W_{Kinetic-Real} = \frac{J}{2}(\omega_k^2 - \omega_{k-1}^2) = -6{,}7 \cdot 10^3[J]$$

The electricity taken over by the GSMP, in the same time frame, is:

$$W_G = \frac{J}{2}(\omega_k^2 - \omega_{k-1}^2) = 2{,}47 \cdot 10^5[J]$$

The wind energy captured by TV has the value:

$$E(35) = \int_{40}^{75} P_{TV} dt = 2{,}4 \cdot 10^5[J]$$

It is noted that it is satisfied,with an error of $1{,}664 \cdot 10^{-5}[\%]$ energy conservation relationship:

$$E(35) = \int_{40}^{75} P_{TV} dt = W_G + W_{Kinetic-Real}$$

3.Results and significances

The operation of the system, having as its input size the value of the wind speed, is in permanently assessed by speed measurements and electrical energy cut on the ranges of sampling. This is why it is necessary to implement an algorithm to adjust.

Adjustment algorithm

The adjustment is based on the estimation of captured wind energy and the metering of energy

electric spuped by GSMP.

Wind energy captured, on the range $\Delta t = t_k - t_{k-1}$ by TV, on the time interval $\Delta t = t_k - t_{k-1}$ the energy balance can be estimated:

ENERGY EOLIANA=VARIATIA OF CINETIC ENERGIES + GSMP DEBITATE ELECTRICAL ENERGY

The basic sizes to be measured are:

1) wind speed - to determine MPP coordinates;

2) momentary VUM - to identify system status;

3) electric energy charged in the sampling range.

These sizes are easily measurable and particularly useful, thus avoiding system management,the use of mathematical models that are often not valid. By measuring the wind speed over time, the optimal VUM can be calculated from the point of energy view and comparing it with the current VUM is required power at the terminals genenerator . From the power is obtained the value of the optimal current: $I_{CCoptim}$. It is presented, in and a direct link between the wind speed value and the dc value.

The adjustment algorithm is based on VUM and energy measurements at GSMP.

The adjustment algorithm for maintaining the system in the optimal energy zone contains

the following steps, for each sampling interval $\Delta t = t_k - t_{k-1}$:

-*step 1* - wind speed measurement and VUM determination $\omega_{OPTIM-t_k}$

-*step 2* - measuring VUM from GSMP and calculating the variation in real kinetic energy

$$W_{Kinetic-Real} = \frac{J}{2}\left(\omega^2(t_k) - \omega^2(t_{k-1})\right)$$

-*step 3* - estimation, within the analyzed time frame, of the wind energy captured

$$E(t_k \div t_{k-1}) = W_G(t_k \div t_{k-1}) + W_{Kinetic-Real}$$

where: $W_G(t_k \div t_{k-1})$ - energy taken by the generator in the sampling range

-*step 4* - estimation of the variation in kinetic energies needed to bring the system to $\omega_{OPTIM-t_k}$

$$W_{Kinetic-Required} = \frac{J}{2}\left(\omega^2_{OPTIM-t_k} - \omega^2(t_{k-1})\right)$$

-*step 5* - estimate of the energy to be picked up by the generator to bring the system to the VUM $\omega_{OPTIM-t_k}$

$$W_{Kinetic-Required}(t_k \div t_{k-1}) = E(t_k \div t_{k-1}) - W_{Kinetic-Real}$$

-*step 6* - calculation of the average power of the generator corresponding to the required energy previously estimated

$$P_{Gmediu} = \frac{W_{Kinetic-Required}(t_k \div t_{k-1})}{\Delta t}$$

-*step 7* - calculation of the load to the generator from the previously calculated average power

$$P_{Gmediu} = 5 \cdot 10^3 \omega^2 (5R + 8) \cdot \frac{4\omega^2 + 6 \cdot 10^2 R^2 + 2 \cdot 10^3 R}{(1{,}25 \cdot 10^3 R^2 + 10^3 R + 7\omega^2)^2}$$

,with solution: $R_k = R_{GSMP-Required-t_k}$

-*step 8* - calculation of power at generator terminals

$$P_{G-borne-t_k} = I_{CCoptim} \cdot U_{CCoptim}$$

Where: $I_{CCoptim}$ and $U_{CCoptim}$ - optimal current, i.e. voltage, in the intermediate circuit of the converter.

The value of the current $I_{CCoptim}$ is achieved by ordering the converter's zippers between the generator and the network, figure 2

By measuring the wind speed with the anemometer an figure 3,

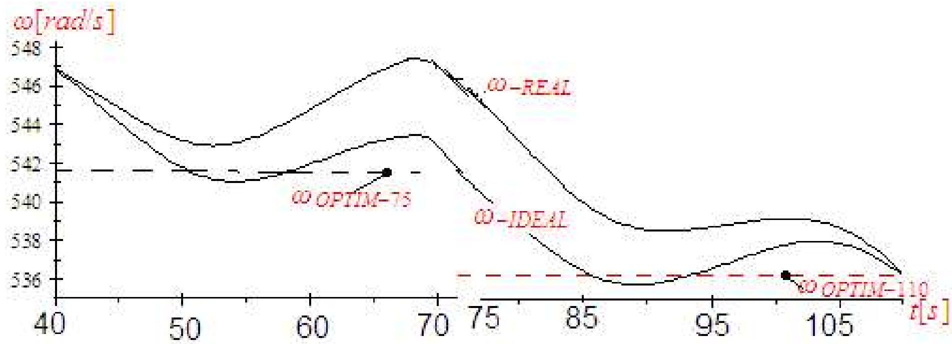

Figure 3. The time variation of real and ideal VUM

determine the value of the current $I_{CCoptim}$. Compare $I_{CCoptim}$ with value measured I_{CC} current and their difference:

$$\Delta I = I_{CCoptim} - I_{CC}$$

is the input size of the regulator R. The output size of the R regulator is transmitted to the switching elements in the power converters between the generator and the network. It is achieved, thus operating in the optimal area from an energy point of view, in conditions where the wind speed varies significantly over time.

Simulations can estimate the value of the current at which the system operates at $I_{CCoptim}$, but it takes time and at variable wind speeds over time the value I_{CC} current must be determined in a short time.

In order to achieve reduced adjustment times it is necessary to find a link between wind speed and

value of the current I_{CC}.

Because the maximum power of the TV, $P_{TV-max}(V) = k_p \cdot V^3$,depends on the wind speed cube can estimate the power in the intermediate circuit in the form of:

$$I_{CC} \cdot U_{CC} = k_{cc} \cdot V^3$$

or: $I_{CC} = k_I \cdot V_{ECH}^3$ where: k_I - the constant of the TV+GSMP group; V - wind speed.

In conclusion, the current in the converter's DC circuit is calculated from the wind speed with the relationship: $I_{CC} = k_I \cdot V^3$. In this way the adjustment can be done in a timely manner and ensure scan in the optimal area.

Equivalent wind speed, over the time interval $\Delta t = t_k - t_{k-1}$, based on the information in the

[1], is calculated with the relationship:

$$V_{ECH} = \sqrt[3]{\frac{1}{T}\int_{t_{k-1}}^{t_k} \left(V(I)\right)^{3,56} dt}$$

4.Conclusions

Through the simulations presented we were able to observe the evolutions over time of the important sizes of the process: currents, speeds, powers, by imposing the load on the GSMP. The best results are obtained by imposing the value of the optimal load current, $\boldsymbol{I_{CCoptim}}$. By knowing the value of the optimal load current, it is possible to adjust the charging to the generator so that a maximum energy operation is carried out. Speed of wind speed variation over time and the value of the moment of inertia are two fundamental elements of which depends on the operation in the MPP area. By prescribing the value of the continuous current, $\boldsymbol{I_{CCoptim}}$, from the intermediate circuit of the converter can be made a simple and useful adjustment of the system determined by wind speed TV_GSMP. Method of control of operation in the optimal area, from an energy point of view of TV, is based on knowledge of the value of the current Icc, which is and momentary mechanical angular speed,VUM.

By analysing several cases, it was possible to determine the basic sizes leading to a optimal operation By measuring the wind speed, the VUM and calculating the current of the task optim, we can perform a functioning in the optime area from the point of view of energy. Adjustment algorithm, based on energy balances made with VUM measurements and electricity, has been validated by simulations.

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