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# THE IMPACT OF THE WIND SPEED ON THE DYNAMICS OF THE WIND ENERGY SYSTEM

**Florențiu DELIU, Petrică POPOV, Paul BURLACU**

**"Mircea cel Bătrân" Naval Academy, Constanța, Romania**
**deliuflorentiu@yahoo.com, petrica.popov@anmb.ro, paul.burlacu@anmb.ro**

***Abstract:*** *The paper analyzes the operation of electric power subsystem consisting of the naval marine wind turbine, the synchronous generator and the electric accumulators at linear and exponential variations of wind speed. The management system is analyzed using various functions of wind speed variation. This subsystem requires to capture the wind energy with maximum efficiency, so a diesel engine and a synchronous generator subsystem can be used only as a complementary source of energy.*

**Keywords: wind subsystem, wind speed, optimal operation**

## 1. Introduction

The study of naval equipment operating with renewable energy sources is desirable, necessary and with a large economic impact. In this respect, the question of saving energy on sea and river vessels is very important. Renewable energy sources used on vessels are mainly of two types: wind and solar power, both having a significant value and complementing each other. In this way, the propulsion will not depend exclusively on oil and can become very profitable in the medium and long terms. This is an important opportunity for the near future, especially for the technological developments in electrical storage batteries where the energy storage is relevant (mentioned as the new LI-ion batteries, approximately 10 times more efficient than lead).

## 2. Wind system management for exponential variations of wind speed

A naval wind turbine is analyzed in order to establish its mechanical characteristics for different values and evolution modes of the wind speed.

At $v = 10[m/s]$ and assuming that turbine torque has the expression:

$$M_{NWT} = -0.5\omega_{NWT} + 20\left(V/5\right)^{1.5} \quad (1)$$

with- $\omega_{NWT} = ct = 20[rad/s]$,

$$M_{NWT(10)} = -0.5\omega_{T} + 20\left(V/5\right)^{1.5}$$

$$M_{NWT(10)} = 46.569[Nm]$$

At exponential change of wind speed, the dynamics of the subsystem wind speed change from:

$v_0 = 5[m/s]$ at $v_1 = 10[m/s]$ is analysed in what follows.

The wind speed does not change suddenly, and at an exponential variation over time, it is represented by the expression:

$$v(t) = 10 - 5e^{-8t} \quad (2)$$

With this specification that torque $M_{NWT}$ shall be amended as follows:

$$M_{NWT}(t) = -0.5\omega_{NWT} + 20(2 - e^{-8t}) \quad (3)$$

and the synchronous generator couple has the expression:

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$$M_{SG}(t) = \frac{20}{314}[-0.5\omega_{NWT} + 20(2 - e^{-8t})]$$

and angular velocity to the synchronous generator is: $\omega = \frac{314}{20}\omega_{NWT}$

The couple $M_{SG}$ will have the form:

$$M_{SG}(t) = 0.063 \cdot \left[-0.5 \cdot 0.063\omega + 20(2 - e^{-8t})\right]$$

or: $M_{SG}(t) = 0.063\left[-0.031\omega + 20(2 - e^{-8t})\right]$

Using the equations of synchronous generator operation and its nominal parameters (figure 1), the following values are shown:

- $R_d$ = 1,6[Ω] - stator winding resistance;
- $R_D$ = 7,95[Ω] - *d* axis damping winding resistance;
- $R_Q$ = 30,22[Ω] - *q* axis damping winding resistance;
- $L_D$ = 0,07[H] - self inductance of damping winding for *d* axis;
- $M_{Dd}$ = 0,05[H] - mutual inductance between stator winding *d* and winding D;
- $L_Q$ = 0,25[H] - self inductance of damping winding from *q* axis;
- $M_{Qq}$ = 0,053[H] - mutual inductance between stator winding *q* and winding Q;
- $L_d$ = 0,07[H] - self inductance of stator winding for *d* axis;
- $L_q$ = 0,08[H] - self inductance of stator winding from *q* axis;

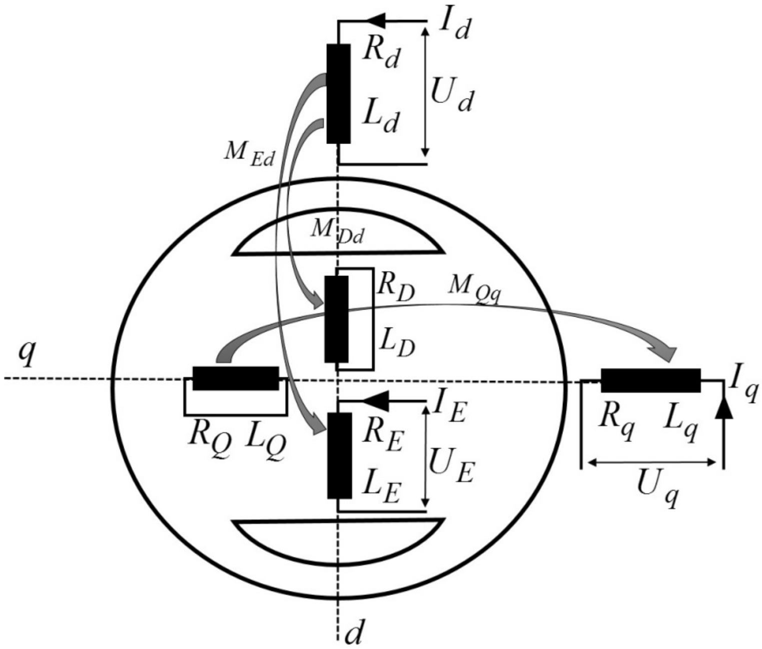


*Figure 1. Windings scheme of synchronous generator*

A permanent magnet is characterised by magnetic flux $\Psi_{PM} = 1.3[Wb]$. In the case of $L_d < L_q$ condition, the inductances are ; ; $L_Q$; $M_{Qq}$; ; $L_q$ will determine the duration of the transient electromagnetic process.

The final condition at wind speed is *v = 10[m/s]*, derived from the function system:

$Q = 0,\ V = 10.0[m/s],\ \cos\varphi = 1,$

$P = 1596.9[W],\ U_d = 98.182[V]$

$U_q = 1145.0[V],\ R = 826.97[\Omega]$

$U_R = 663.47[V],\ f = 141.42[Hz]$

$\omega_{NWT} = 56.569[rad/s],\ \omega = 888.13[rad/s],$

$\Psi_{PM} = 1.3[Wb],\ \Psi_S = 1.2994[Wb],$

$I_R = 0.80230[A],\ I_d = -0.11873 \times 10^{-2}[A],$ .

For the wind speed *v = 10[m/s]* specific values for $P_{max}$ are obtained:

$I_d(\infty) = 0.11873$ [A]

$I_q(\infty) = 1.3845$ [A]

$U_d(\infty) = 98.182$ [V]

$U_q(\infty) = 1145$ [V]
$\omega(\infty) = 888.13$[rad/s]
$R(\infty) = 826.97[\Omega]$

Switching the subsystem wind from *v = 10[m/s]* at *v = 10[m/s]*, the two-degree system of differential equations can be analyzed, solved by numerical methods, (with MAPLE-soft).

## 3. Exponential variation

The wind speed will be considered varying exponentially, according to the relation: $v(t) = 10 - 5e^{-8t}$

Achieving value stationary (I = 1.4 [A]) takes place in a relatively large amount of time, taking into account the possibilities of the MAPLE calculation program. For this reason it has got a small time interval 0 - 0.001 [s], especially that at this time you can very clearly see the evolution over time of the current. $I_Q$ will be "extinguished" in 0.06 [s], with small values (less than 0.003 [A]).

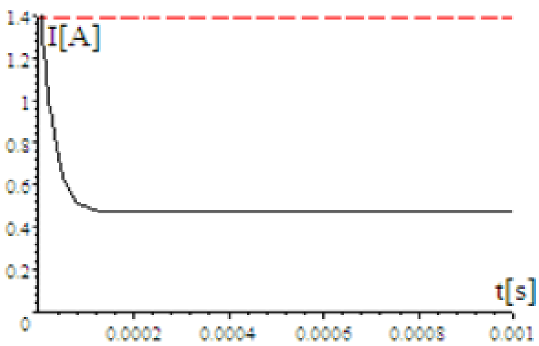


*Figure 2. Variation in time of the current windings*

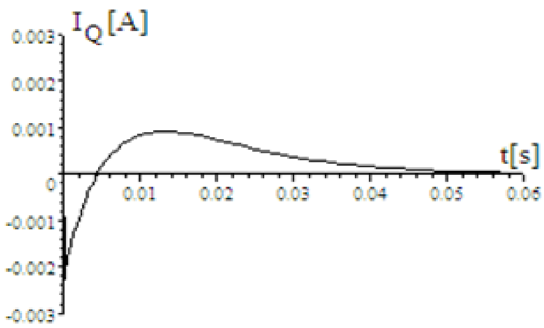


*Figure 3. Variation in time of current $I_Q$*

The dependence of the current windings can be observed at the beginning of the process. The current depreciation of the axis, $I_D$ is "off" at the same time, but has higher variation, reaching 1.1 [A] in the vicinity.

The angular velocity in shaft rotor angular-synchronous generator grows slowly from the initial value $\omega_{(0)} = 314$[rad/s], the final amount being $\omega_{(0)} = 888$[rad/s].

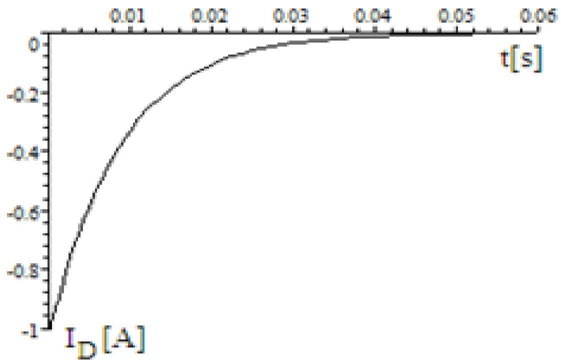


*Figure. 4. Variation of $I_D$ current in time*

The electromagnetic torque:
$M_{elmg} = -0.01 I_d I_q + I_q 1.3 - 0.053 I_d I_Q + 0.05 I_q I_D$
changes from the initial value: $M_{elmg}(0) = -0.6[Nm]$
to the final amount:
$M_{elmg}(\infty) = -1.8[Nm]$ in a time interval of seconds.

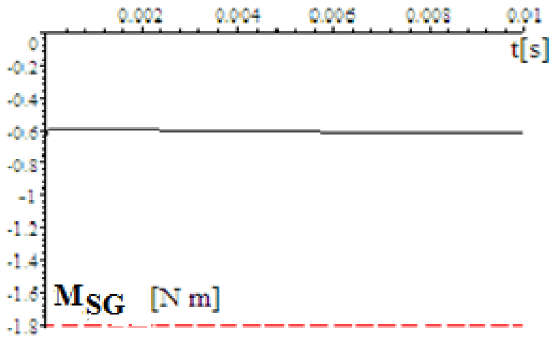


*Figure 5. Variation of electromagnetic torque*

Due to the inertia moments ($J = mr^2$), large mechanical processes are slow, and so the current wind speed changes are "redeemed" by the naval wind turbine. The electrical power is obtained and the pulses depend on the wind speed to power the third if the operation takes place at the point of maximum power, but how the (naval wind turbine + synchronous generator + electric accumulators) is due to the great moments of inertia, an important component of mechanical operation of the high inertial point of maximum power is not always possible. Moreover, it can be seen that the operation subsystem is not optimal for most periods of time. The operation at the point of maximum power is not always possible.

Considering the optimal initial operation at wind speed $v_1$ (at ), at the point $P_1$ and modifying the wind speed at $v_2$, then operating point moves in $P_i$, the angular velocity at the turbine axis does not change due to mechanical inertia.

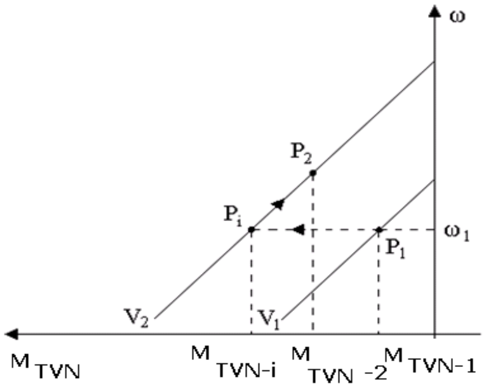


*Figure 6. Modifying the operating point*

Knowing the system solutions and solving the equation:

$$P_{NWT} = \omega_{NWT}\left[-0.5\omega_{NWT} + 20(V/5)^{1.5}\right]$$

Important sizes are determined at the point of maximum power $P_1$:

$P_{NWT} = 200[W]$-mechanical power of naval wind turbine;

$P_{SG} = 199[W]$-the power given by the synchronous generator;

$\omega_{NWT} = 20[rad/s]$-mechanical angular velocity at naval wind turbine;

$U_R = 235[V]$- the voltage at the terminals of the synchronous generator;

$I_R$ = 0,28[A]-current of synchronous generator;

f = 50[Hz]-the frequency of the synchronous generator;

$\Psi_S = 1.3[Wb]$-windings flux of synchronous generator.

The wind speed *v = 10[m/s]* mechanical characteristic change of naval wind turbine, and the couple so that the synchronous generator is amended. As mentioned above, due to the mechanical inertia, it is considered to be constant ($\omega_{NWT} = 20[rad/s]$), and so to obtain the algebraic system of equations below, where there is no adjustment system and hence resistance equivalent to the terminals of the synchronous generator has the same value as the *v = 5[m/s]* $R = 830.97[\Omega]$.

System solutions are:

$\Psi_S = 1.2996[Wb]$, $f = 50[Hz]$,

$Q = 0[VAR]$, $\Psi_{PM} = 1.3[Wb]$,

$\cos\varphi = 1, \omega_{NWT} = 20[rad/s]$,

$V = 10[m/s]$, $R = 830.97[\Omega]$,

$M_G = -0.63694[Nm], U_d = 12.283[V]$,

$P = -199.62[W]$, $U_q = 407.09[V]$,

$U_R = -235.14[V]$

$I_d = -1.4781\times10^{-2}[A], I_R = -0.28297[A]$,

$M_{NWT} = 2.9661[Nm]$,

$I_q = -0.48990[A]$, $P_{NWT} = 931.37[W]$,

$\omega = 314[rad/s]$.

The system works on the final speed *v = 10[m/s]* and $\omega_{NWT} = 20[rad/s]$, result:

$P_{NWT} = 931[W]$; $P_{SG} = 199[W]$; $U_R = 235[V]$;

$I_R = 0.28[A]$; $M_{SG} = 0.6[Nm]$;

$M_{NWT} = 2.9[Nm]$.

## 4. The subsystem dynamics at linear variation of wind speed

We consider the linear changing of wind speed *v(t)=5+t* through changing of wind speed from 5[m/s] to 10[m/s], and management system changes the value of equivalent resistance from terminals. The system solutions represent the measurement values of maximum power point to *v = 10[m/s],* R= 826,97 [Ω] and $\dot{\omega}$= 20 [rad/s], namely:

$\Psi_S = 1.2996[Wb], f = 50[Hz],$
$Q = 0[VAR], \Psi_{PM} = 1.3[Wb],$
$\cos\varphi = 1, \omega_{NWT} = 20[rad/s],$
$V = 10[m/s], R = 826.97[\Omega],$
$M_G = -0.64001[Nm], U_d = 12.342[V],$
$P = -200.58[W], U_q = 407.08[V],$
$U_R = -235.14[V], I_d = -1.4924 \times 10^{-2}[A],$
$I_R = -0.28434[A], M_{NWT} = 2.9661[Nm],$
$I_q = -0.49226[A], P_{NWT} = 931.37[W],$
$\omega = 314[rad/s].$

The most important measurement results are: $P_{NWT} = 931[W]$; $P_{SG} = 200[W]$; $U_R = 235[V]$ $I_R = 0.28[A]$; $M_{SG} = 0.64[Nm]$; $M_{NWT} = 2.96[Nm]$

Passing to *v = 10[m/s],* it can be observed through simulation with the mathematical model, using a mechanical characteristic of naval wind turbine having the form:

$$M_{NWT} = \left(-0,031\omega + 20\left(1.+t/5\right)^{1.5}\right)0,063$$

Variation of the stator current

$$I = \sqrt{I_d^2 + I_q^2}$$

depending on time is given in figure 7.

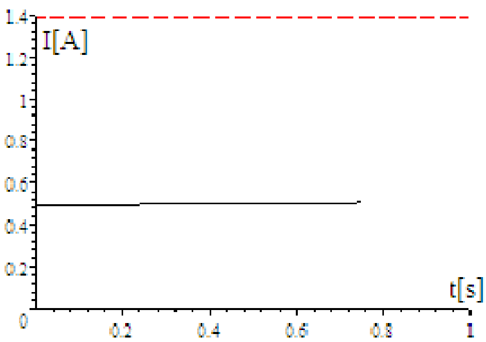


*Figure 7. Time variations of the stator current*

The current axis damping q, $I_Q$ , has very low values, the processes are very slow in electromagnetic terms and the moment of inertia equivalent is high. Because of these small values of the damping current, the calculations stop under 0.8[s], the simulation program being equipped with limitations in accumulation of errors.

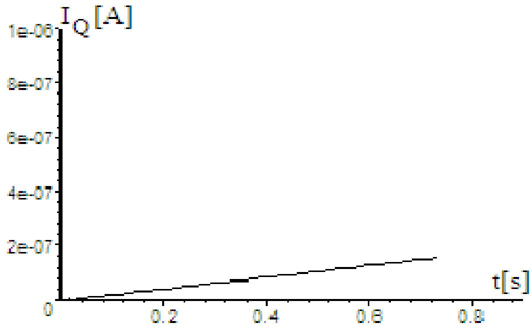


*Figure 8.Time variations of the stator current $I_Q$*

The current damping axis *d*, $I_D$ in a similar way with $I_Q$ has values small values, so basically rotor damping winding does not ''feel'' in transitional processes.

## 5. Conclusions

In the electric power systems of the ships, it is essential that the analysis of transient phenomena occurring in the subsystem operation (naval wind turbine, synchronous generator and electric accumulators) should be made.The operational stability is determined by the wind velocity in time while the management system can be stable or unstable even in static operating points. Therefore, for the operation of such a system in operation maximum points, we have to take into account: the load resistance dependence of the wind speed in static and dynamic states; the transient analysis at wind speed variation; maximizing electric power while the wind speed varies, and the calculation of the reference speed must be made so that the energy is taken for the maximum wind speed.

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