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SYNCHRONOUS GENERATOR’s ROTOR INVESTIGATION OF A HYBRID POWER SYSTEM INCLUDING A.G.

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Abstract: *An energy weak grid consisting of a wind energy conversion system (WECS) which includes an asynchronous generator and a conventional plant consisting of diesel motor - synchronous generator unit, is analyzed. This system has been simulated via a developed general dynamic mathematical model which analytically describes the electric subsystems. Some interesting simulation results are presented in this paper. Specific attention is paid to the investigation of the dynamic analysis of the S.G.’s rotor at the connection and the disconnection of different nominal power WECS to the conventional plant and for a three phase short circuit.*

KEY WORDS: *Energy weak grid, WECS, Simulation, Dynamic Behavior, Hybrid System.*

1 Introduction

Wind is a significant and valuable renewable energy source and a remarkable progress has been made over the past decade. WECS is already one of the most cost – competitive renewable energy technologies. Today, the cost is about 3 to 4 cents per kWh in USA, but in 1986 it was about 11-17 cents per kWh, respectively. The total cost of wind energy conversion system is brought to 850 – 1000 € per kW of installed capacity. The rapid decrease of the cost and the ecological and social benefits lead the wind power to be one of the world’ s fastest growing energy sources. For example, in the end of 1996 around 3,5 GW of WECS capacity had been installed in Europe [9]. Eight years later around 25 GW be installed. Energy storage can be a cost – effective component of hybrid remote power systems. These systems are installed in small or medium size islands with good wind conditions or at the conventional grid. For this reason, the under investigation weak energy system that is modeled in this paper is a Wind – Diesel Hybrid System without energy storage. In view of the weak grid characteristics, the use of this kind of systems requires appropriate control systems for the solution of instability and power quality problems. To obtain a large wind penetration, via the optimal exploitation of the wind potential, without problems for the electrical subsystems of the weak energy system and for the consumers, two control systems for the Diesel - S.G. unit are necessary.

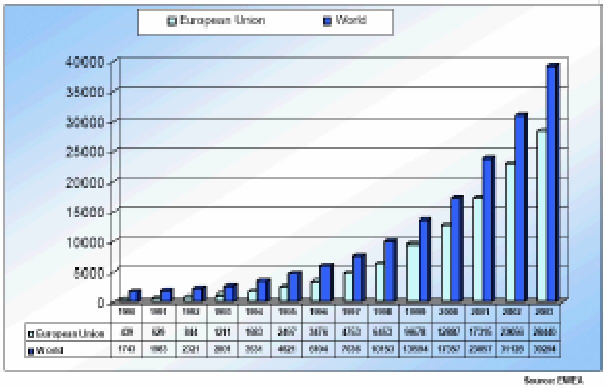

Fig. 1: Cumulative Wind Energy Installed Capacity [10]

By acting on the control the conventional unit operates in such a way that the fuel consumption and the excitation voltage get new values in relative to the electrical power that the WECS provides.

Analytically, this system consists of a unit of Diesel–Synchronous Generator and a unit of a wind motor and an asynchronous generator. There is also three control systems, one for active power – frequency control, one

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for control of the excitation voltage – stator voltage of the synchronous generator, and one for control of the angular velocity of the wind energy conversion system.

2 Description of the weak energy system

General hybrid systems are the most efficient for supporting the energy production and distribution system. It is known that the control systems in energy production and distribution are necessary for the stable and optimal operation of the whole energy system. The variations of the electrical power produced from the synchronous generator significantly depend on the wind - asynchronous generator operation.

This is the reason why the hybrid systems are characterized as intelligent power systems (I.P.S.). In order to encounter the variations, automatic control systems are used for the synchronous - diesel unit and the wind motor - asynchronous generator unit.

Fig. 2 shows the analytical structure of the weak hybrid power system. It is comprised of a Diesel motor and a synchronous generator, an ohmic-inductive load which stands for all the particular loads, a transformer and a short distance line (R-L) since the distances between the plant and loads in islands are considered short.

The system that converts the wind energy to the electrical one includes an asynchronous generator, whose mechanical torque depends on the wind' s velocity and the parameters of the wind motor. In this paper, it is considered that the Diesel - synchronous generator unit supplies the load and operates in the nominal steady state.

In such systems, appropriate control loops of the conventional plant are used to control the frequency and the voltage in order to obtain a stable and safe grid operation in transient condition.

The control is necessary to obtain a production of electrical energy under the state of almost stable frequency and voltage, according to the electrical grids rules. On the other hand, control loops for the rotating velocity of the asynchronous generator included in WECS are also used for stable and optimal operation. For the optimal exploitation of the random varied wind potential a tip speed ratio optimum strategy control loop is used via adjusting the wind turbine's mechanical power.

The regulation of the produced energy of both sources, Diesel unit and wind unit as well, via an intelligent control is effectively obtained.

For the analysis of the whole system analytical equations for the description of the weak electrical grid using analytical Park transformation for the generators and the basic aerodynamic equations for the wind motor are used.

A simulation based on the mathematical model, [5] and [6], was developed and used for the investigation of any dynamic condition. This mathematical model comprised of twenty three differential equations (a lot of them is non linear).

For the purpose of the present investigation, WECS with the nominal power are 1 MW and 2 MW (33% and 67% of the synchronous machines nominal power, if it is 3 MW respectively), are used.

With this overall simulation model any transient condition can be investigated. This is important since it is well known that a qualitative and quantitative analysis of transient behavior is necessary for the power system design.

The main equations which used for the calculation of the S.G.' s rotor variables, are the following :

$$M_{EL} = (p_S / \omega_S)\,[I_{SGd}\,(x_d - x_q) + x_{Fd}\,I_{SF}]\,I_{SGq} \qquad (1)$$

$$M_{EL} = p_S\,(I_{SGq}\,I_{SGd}\,(L_{dd} - L_{qq}) + (L_{fd}\,I_{SF} + L_{Dd}\,I_{SD})\,I_{SGq} - L_{Qq}\,I_{SQ}\,I_{SGd}). \qquad (2)$$

$$T_d' = (L_{ff} - (L^2_{fd}/L_{dd})) / R_F)) \qquad (3)$$

$$T_d'' = [L_{DD} - [(L^2_{hd}/L_{dd})\cdot(1-((L_{dd}-L_{hd})^2 / (L_{dd}\cdot L_{ff}-L_{hd}^2)))]/R_D \qquad (4)$$

$$T_q'' = [L_{QQ} - (L_{hq}^2 / L_{qq})] / R_Q \qquad (5)$$

$$(AS)_{21}(I_{SGT}) + (AS)_{22}\,(I_{SFT}) + (BS)_{21}\,d(I_{SGT}) / dt + (BS)_{22}\,d(I_{SFT})/dt = (U_{SFT}) \qquad (6)$$

The appropriate control loops of the system's conventional part, based on P-I-D- controllers are described through the following transfer functions:

<u>Pact – f control loop:</u>

P controller: $1 / (2\,\pi\,f\,R)$ (7)

I controller: K_I / p (8)

D controller: $K_D\ p$ (9)

Delay of control mechanism and Diesel - S.G.:

$1 / [(1+ p\,T_C)\,(1+ p\,T_S)]$ (10)

p: Laplace variable

<u>U - U_F control loop:</u>

Delay of control mechanism: $1 / (1+ p\,T_R)$ (11)

Amplifier: $K_A / (1+ p\,T_A)$ (12)

Excitation: $K_E / (1+ p\,T_E)$ (13)

Stabilizing loop: $p\,K_F / (1+ p\,T_F)$. (14)

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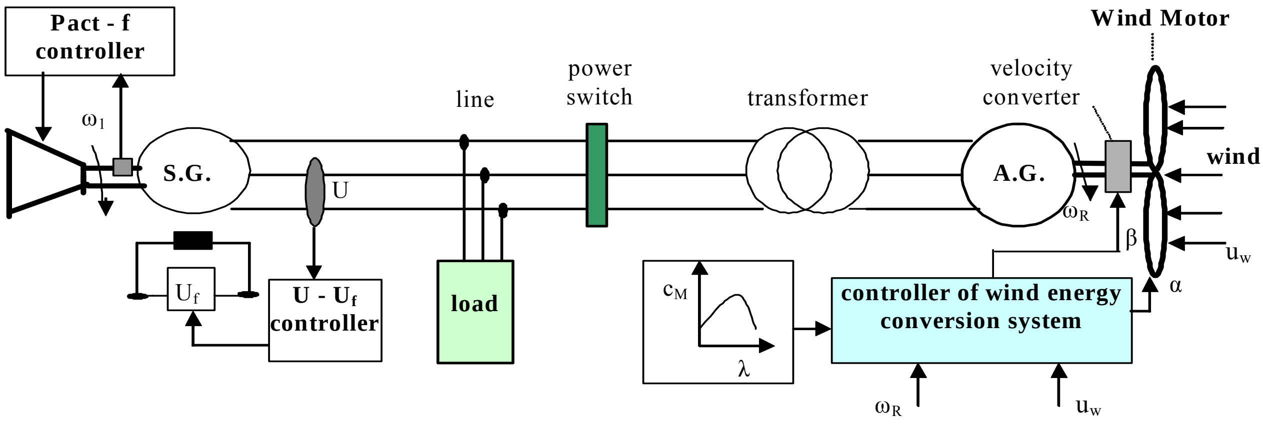

Fig. 2: Basic structure of the weak energy grid.

3 Simulation results

It is obvious that through the developed simulation code we have the possibility to investigate extensively the dynamic behaviour of the weak energy grid's variables, to obtain useful information about the rotor's variables of the synchronous generator, as the dumping current and the excitation current. According to the simulation results of fig. 3a, 6a and 7a, we can see that the maximum deviation of the dumping current of the S.G. is ten times bigger in the case of WECS connection comparison with the variable's deviation at the disconnection proccess.
The dumping current in the case of the short circuit at the S.G.'s output (for 0,5 s time duration) is about 40 and 50 times bigger compared to the disconnection procces.

VARIABLES	*200 KW WECS*	*1 MW WECS*	*2 MW WECS*	*POWER RATIO OF WECS (1:5:10)*
Deviation of the excitation current ΔI_{SF}	2,5%	14,6%	20%	1 : 5,8 : 8
dumping current of the S.G. I_{SDQ}	120 A	380 A	480 A	1 : 3,2 : 4

Table 1: Deviation of the electromechanical variables following the WECS connection to the grid.

The maximum deviation of the excitation current of the S.G. at the three phase short circuit is dumplicated in comparison to the case of disconnection proccess. The same is acceptable for the electromagnetic torque of the S.G. (fig. 4, 5 and 8). The current system' s parameters of the S.G. are:

P_N: nominal power of S.G. (= 3000 kVA)
U_N: nominal voltage of S.G. (= 15,75 kV = U_{ref})
$\cos\varphi_N$: nominal power factor of S.G. (= 0,9)
n_{NSG}: nominal rotation speed of the S.G. (= 428,5 rpm)
p_S: pore pair number of pole of the S.G. (= 7)
ω_{1o}: synchronous angular velocity (= 314,16 rad/s)
U_{FN}: nominal excitation voltage (= 75V)

Parameters of synchronous generator:
R_{FF}= 0.19 Ω, R_{SS}= 0.08 Ω, L_{qq}= 0.028 Ωs, L_{dd}= 0.048 Ωs, L_{Qq}= 0.022 Ωs, L_{fd}= 0.042 Ωs, L_{Dd}= 0.042 Ωs R_D=0.95Ω, R_Q= 0.96Ω, L_{FF}=0.256Ωs, L_{DD}= 0.044 Ωs, L_{fD}= 0.042Ωs, L_{Df}= 0.042 Ωs, L_{QQ}= 0.025 Ωs,

Analytically the parameters of the whole system are presented at [7, 9].
Especially for three cases of transient situations, connection and disconnection of the WECS and at a three phase short circuit at the load, via the simulation results we can point out the following main results:

a) in the initial time after the WECS connection, the deviation of the excitation current currently depends in analog on the nominal power of WECS but the deviation of the S.G.'s dumping current at the case of 2 MW WECS is smaller compared to the value that we waiting for (only 25% bigger). (Table I),
b) The oscillations magnitudes of the system's variables are smaller during the disconnection process compared to the connection process and at the three phase short circuit, but the time needed for the system to get to the new steady state is about the same and
c) The dumping current at the three phase short circuit at the load for 0,5 sec is about ten times bigger compared to the dumping current following the connection of WECS and about 40 and 50 times compared to the disconnection process, respectively.

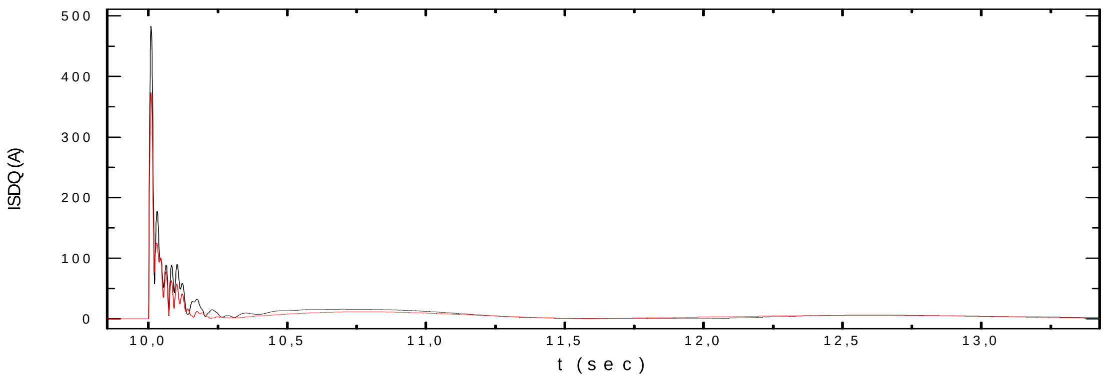

Fig. 3: Deviation of the S.G.'s dumping current at the WECS connection to the weak grid a) 1 MW b) 2 MW

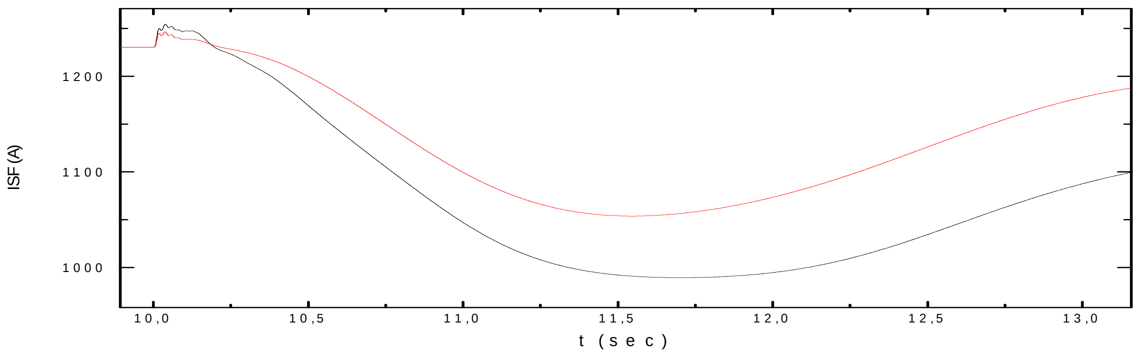

Fig. 4: Deviation of the S.G.'s excitation current at the WECS connection to the weak grid a) 1 MW b) 2 MW

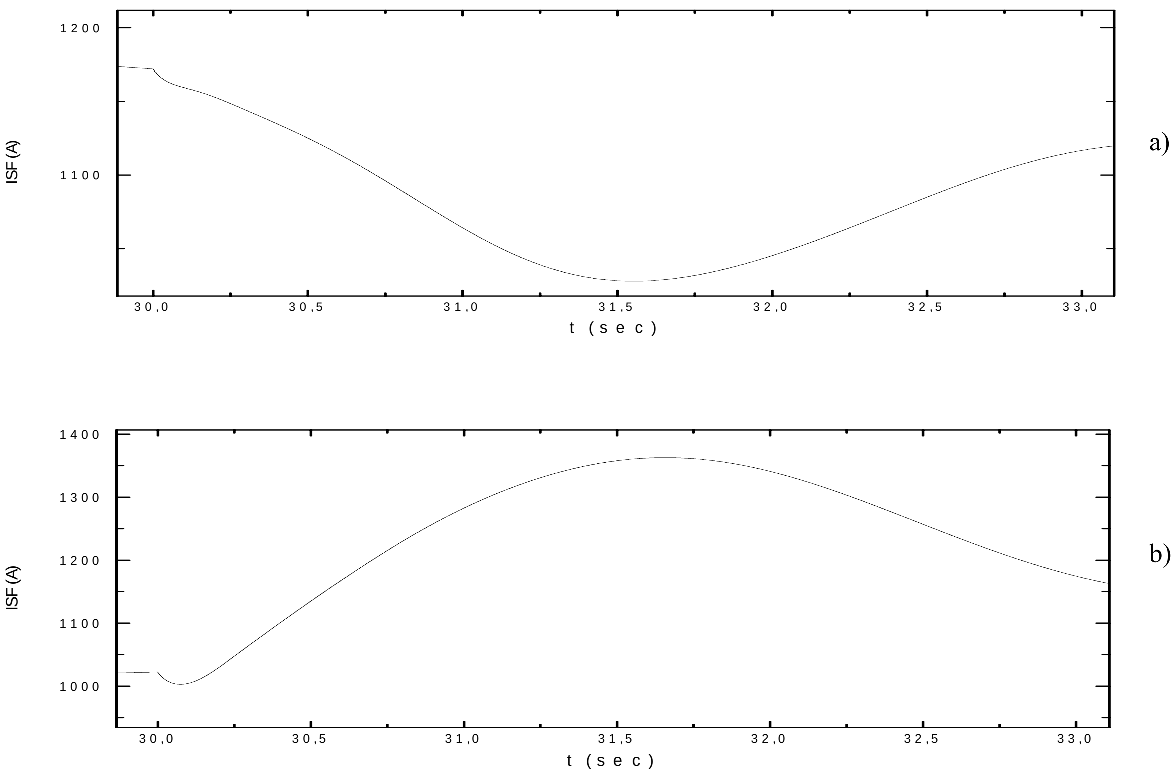

Fig. 5: Deviation of the S.G.'s excitation current at the WECS disconnection to the weak grid a) 1 MW b) 2 MW

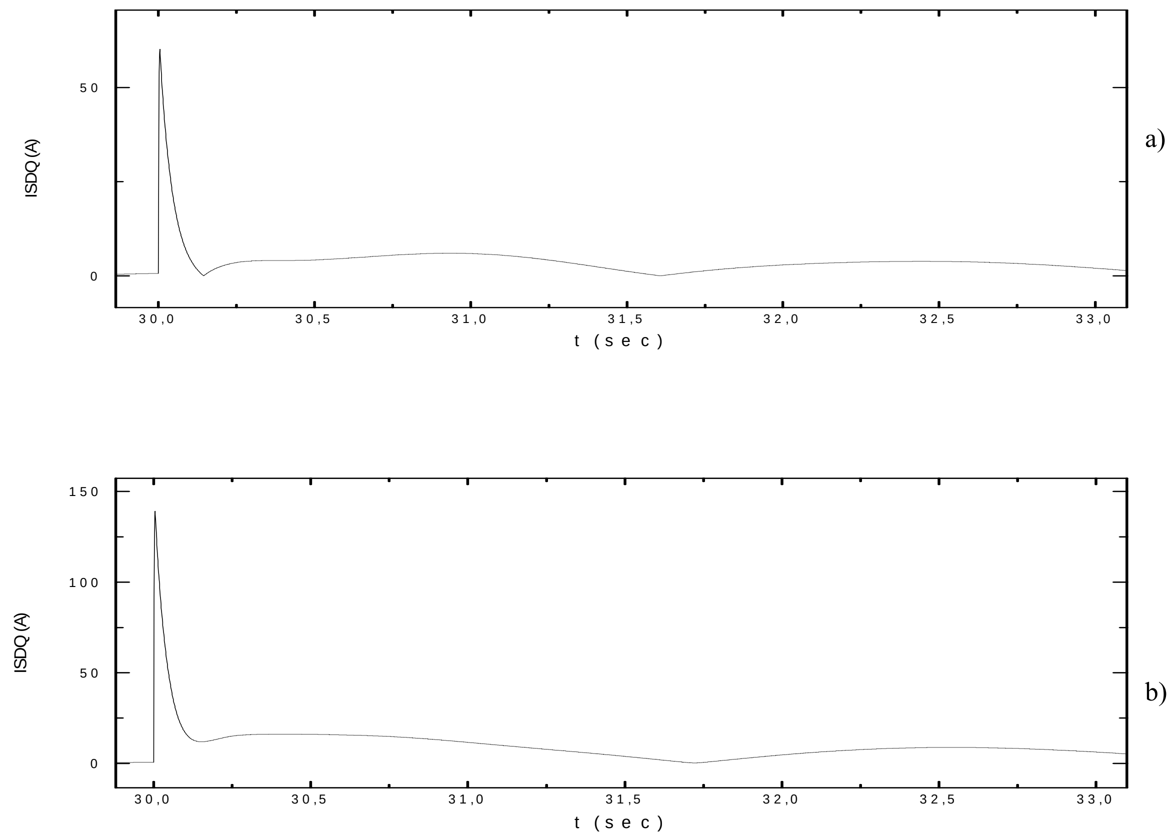

Fig. 6: Deviation of the S.G.'s dumping current at the WECS disconnection to the weak grid a) 1 MW b) 2 MW

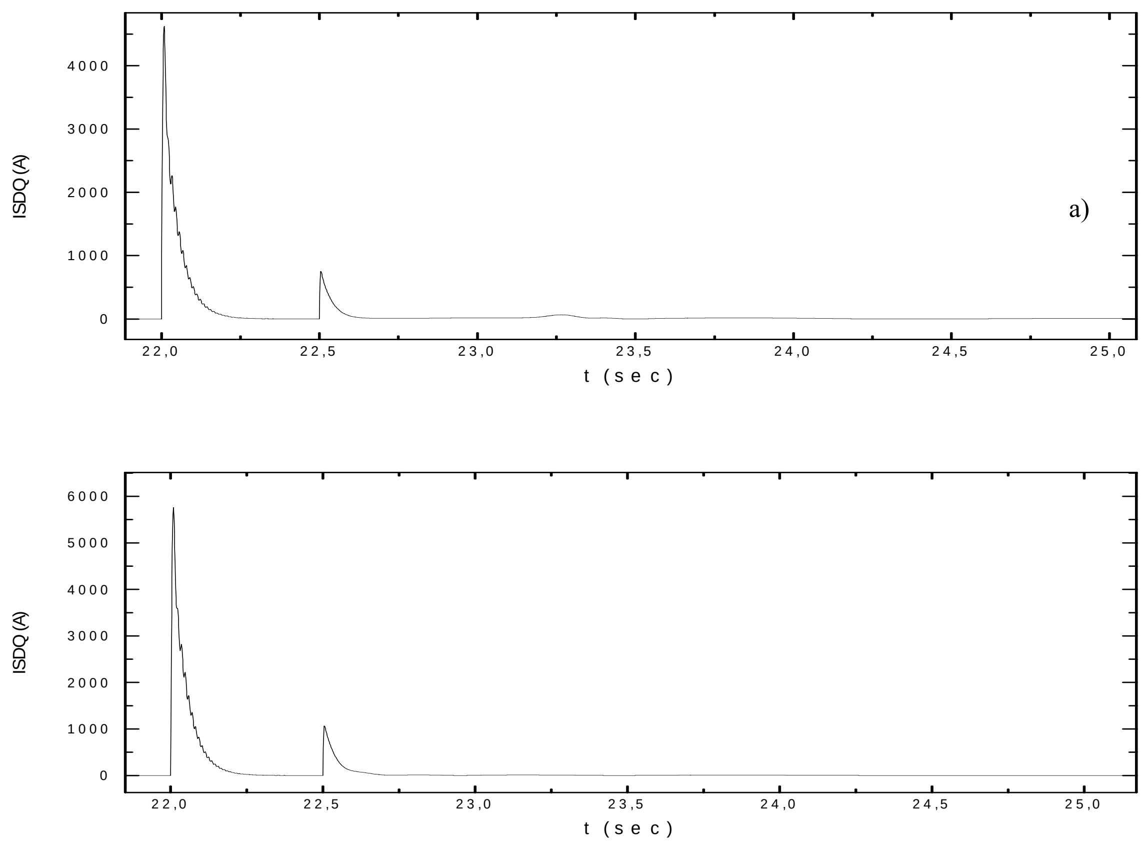

Fig. 7: Deviation of the S.G.'s dumping current at the three phase short circuit a) 1 MW b) 2 MW

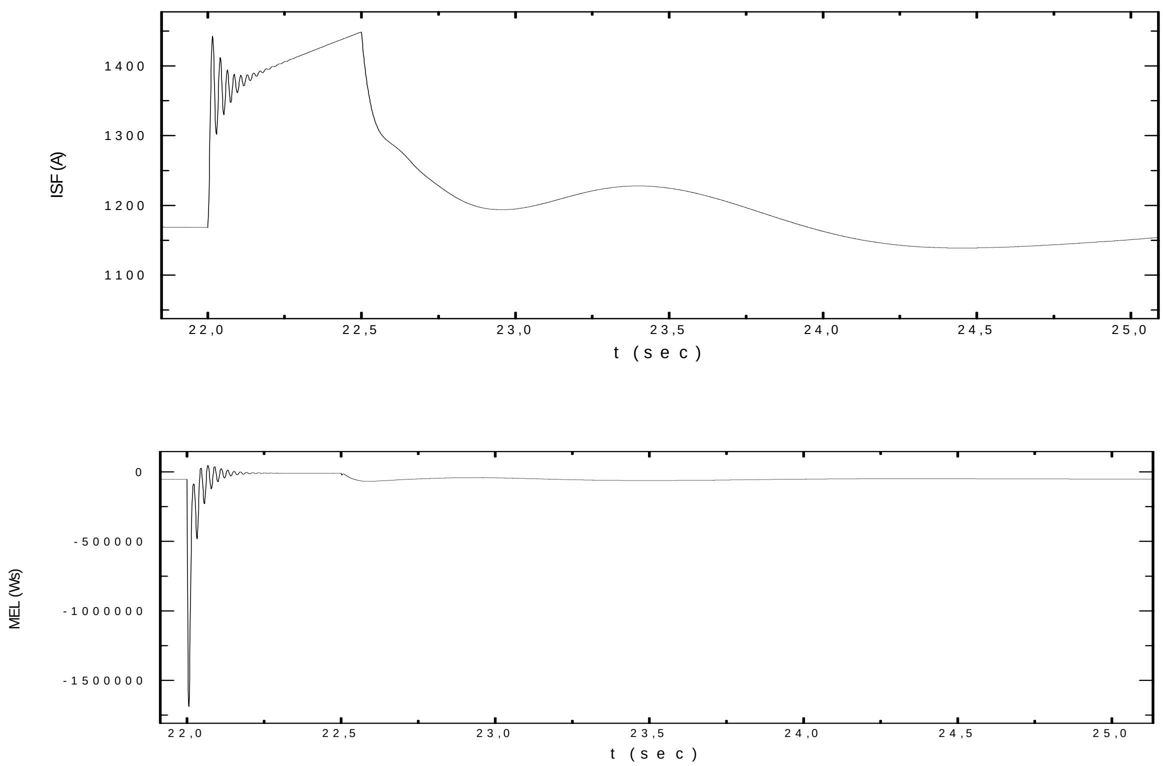

Fig. 8: Deviation of the S.G.'s excitation current and the electromagnetic torque at the three phase short circuit for 1 MW WECS

4 Conclusion

The dynamic behavior of a weak electric network, in which the production of electric energy is based on both fossil fuels and wind power for three characteristic cases, connection and disconnection of the WECS and at the three phase short circuit at the laod, was investigated in this study. A general dynamic mathematical model that can be used to study the behavior of such a system in detail was developed, using Park transformation and basic aerodynamic equations. In general,. we can point out the following main results: a) in the initial time after the WECS connection, the deviation of the excitation current currently depends in analog on the nominal power of WECS but the deviation of the S.G.'s dumping current at the case of 2 MW WECS is smaller compared to the value that we waiting for. b) The oscillations magnitudes of the system's variables are smaller during the disconnection process compared to the connection process, but the time needed for the system to get to the new steady state is about the same and c) The dumping current at the three phase short circuit at the load for 0,5 sec is about ten times bigger compared to the dumping current following the connection of WECS and about 40 times compared to the disconnection process, respectively.

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