INVESTIGATION OF THE DYNAMIC BEHAVIOR FOR A WEAK ENERGY GRID INCLUDING WECS BY THE INTERRUPTION OF THE DIESEL MACHINE'S OPERATION

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ABSTRACT: In this paper a hybrid energy system consisting of a conventional plant (Diesel – Synchronous generator) and a Wind Energy Conversion System (WECS) (wind motor and asynchronous generator) and the appropriate control systems is studied. Specific attention is paid to the investigation of the dynamic behavior of the whole power system at the connection of the WECS in comparison with the case of the interruption of the diesel machine's operation. A general dynamic mathematical model appropriate for the study of this weak energy system is obtained. Via a general simulation using this model some characteristic results of the system for these two characteristic cases are presented.

KEY WORDS: Energy weak grid, WECS, Simulation, Dynamic Behavior, Hybrid Systems, Faults.

1. INTRODUCTION

The generation of electricity by Renewable Energy Sources (RES) does not involve the release of carbon dioxide, acid rain, smog or radioactive pollutants. The use of RES reduces dependency on conventional fossil and nuclear fuels.

A very important application for renewable energy sources, as the Wind Energy Conversion System (WECS) is in conjuction with weak energy grid. General hybrid energy systems are the most efficient for supporting the energy production and distribution system mainly for small islands with good wind conditions. It is well known that the hybrid system control is an application area with an interesting set of problems.

These problems came from the random varied wind potential and the necessity to have a safe operation for the consumer and the machines for special conditions as faults at the excitation of the synchronous generator, at the diesel machines operation, the three phase short circuits and the connection or the disconnection of the WECS to the weak energy grid.

In this paper, it is considered that the conventional plant unit supplies all the particular loads and operates in the nominal steady state.

Three control systems are necessary for the safe and optimal operation of the whole energy system. These control systems are, the active power - frequency control loop (necessary to keep the frequency constant by adjusting the fuel of the diesel motor), the terminal voltage – excitation voltage control loop (necessary to keep the terminal voltage constant by adjusting the excitation current) and the control for the optimal exploitation of the wind potential by adjusting the rotating velocity of the asynchronous generator.

A simulation code based on a general dynamic mathematical model was developed and used for the investigation of any dynamic condition and offers the possibility to study any symmetrical or non symmetrical faults [5,6,7].

Fig. 1 shows the basic structure of the weak power grid including conventional plant (diesel motor – S.G.) and wind energy conversion unit (wind motor – A.G.).

In this paper, simulation results of two characteristic operation cases, a) connection of WECS to the weak energy grid and b) interruption of the diesel machine's operation, are presented and investigated.

2. SIMULATION

The dynamic energy system is described by twenty three differential equations. Most of these are not linear. This general dynamic mathematical model is appropriate for the investigation of any operation state of this weak energy grid. The detailed mathematical model is included in the papers [5,6,7].

For the mathematical analysis of the electromechanical subsystems, the analytical Park's equations are used. For the analysis of the wind motor the analytical aerodynamic equations are used.

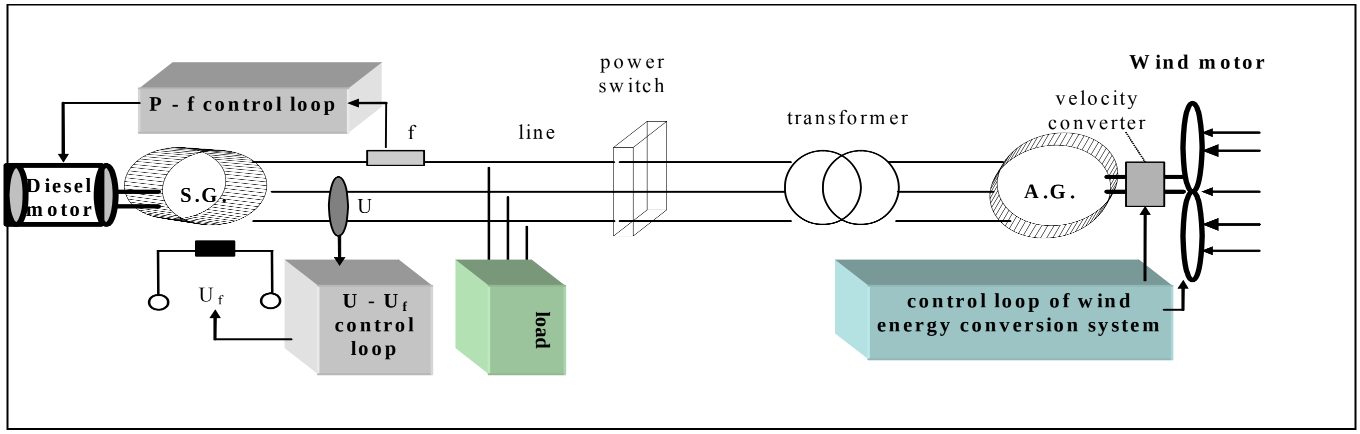


Fig. 1: Basic structure of the weak energy grid.

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

Pac - f:

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

I controller: K_I / p (2)

D controller: $K_D\ p$ (3)

Delay of control mechanism: $1 / (1+ p\ T_C)$ (4)

Delay of Diesel - S.G.: $1 / (1+ p\ T_S)$ (5)

Preac - U control loop:

Delay of control mechanism: $1 / (1+ p\ T_R)$ (6)

Amplifier: $K_A / (1+ p\ T_A)$ (7)

Excitation: $K_E / (1+ p\ T_E)$ (8)

Stabilizing loop: $p\ K_F / (1+ p\ T_F)$. (9)

The Control loop for the WECS are described through the following equations:

$T_{AN}\ dx/dt= -K_{AN}V_{wo}-(K_{AN}V_{w1}+1)x+(K_{AN}/T_{AN})V_{w1}$ (10)

$(J_A/p_A)\ d(\omega_R)/dt = M_{MA} - M_{EL}$, (11)

$M_{MA}= Q\ C_M(\lambda) / K_A$ (12)

$Q = 0.5\ \rho\ \pi\ R^3\ V_w^{\ 2}$ (13)

$T_{AS}\ d\beta /dt = K_{AS}\ (\lambda - \lambda_{opt})$ (14)

$K_{Anew} = K_{Aold} / (1-\beta)$ (15)

All the above equations, with the part which consists of the asynchronous generator – line – transformer, are described in form of hypermatrices as in eq. (16).

$(K)\ d(AGN)/dt = (\Lambda) * (AGN) + (M) * (GN)$ (16)

The matrices (K), (Λ) and (M) are presented in [7].

The system under research is simulated by means of Runge - Kutta numerical method of fourth order which was developed in Turbo Pascal code.
This general dynamic mathematical model can be applied for any weak energy system which includes WECS and offers the possibility to investigate any transient and steady state operation.

3. SIMULATION RESULTS

The simulation results in the case of interruption of the diesel machine's operation for 0,5 sec at a nominal state operation (fig. 2) are shown. The system' s parameters are mentioned in the nomeclature of this paper.
According to these simulation results, we can see that the deviation of the variables of the weak energy grid is stronger in comparison to the deviation of the variables via a short cirquit at the excitation of the synchronous generator for 0,5 sec, respectively [8].
Also, we can remark that the deviation of the variables in this case is stronger in comparison to the deviations at the case of the junction of 1 MW WECS or 2 MW WECS connection to the weak energy grid for nominal wind velocity (fig. 3).

Anallytically:

a) The maximum deviation of the rotating velocity of the asynchronous generator (ω_r) at the interruption is 36% higher in comparison to the nominal value but the maximum deviation of ω_r is 10% higher in the case of the junction of 1 MW WECS (Wind Energy Conversion System) to the weak energy grid, respectively.

b) The maximum deviation of the electromagnetic torque of the asynchronous generator (M_{ELA}) at the interruption is 200% higher in comparison to the nominal value and in the case of the connection of 1 MW WECS to the weak energy grid is 150% higher, respectively.

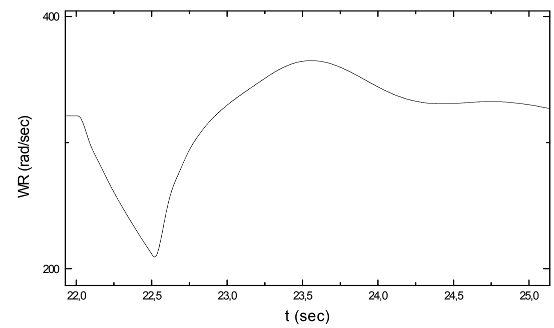
c) The maximum deviation of the rotating velocity of the synchronous generator (ω_1) at the interruption is 36% higher in comparison to the nominal value and in the case of the connection of 1 MW WECS to the weak energy grid is 10% higher, respectively. After 3 seconds ω_1 is tends to take zero value.

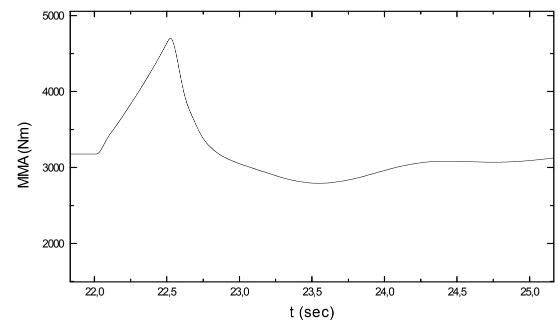
d) If the time duration of this fault is bigger than two (2) seconds the weak power system cannot be came back to a new steady state operation.

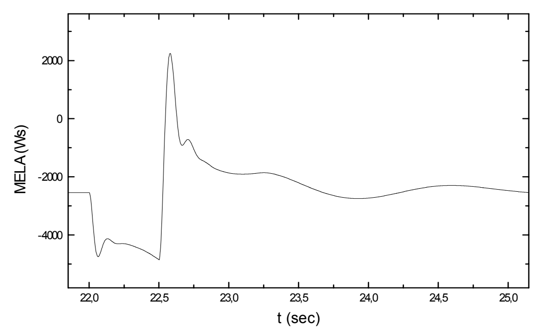
e) In the case that the time of this fault is smaller than 0,5 sec the deviation of the variables of the system is smaller in comparison to the case of 1 MW WECS connection to the weak energy grid.

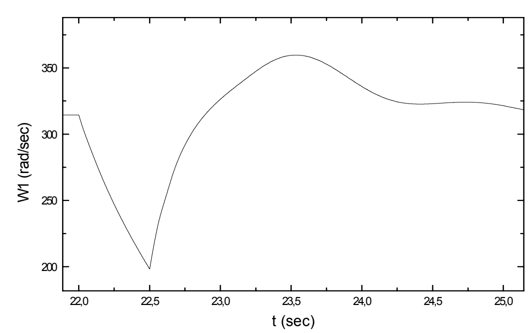
f) The deviation of the excitation current of the synchronous generator via the interruption of the diesel machine's operation is 120% higher in comparison to the nominal value and in the case of the connection of 1 MW WECS to the weak energy gird is 83% higher respectively.

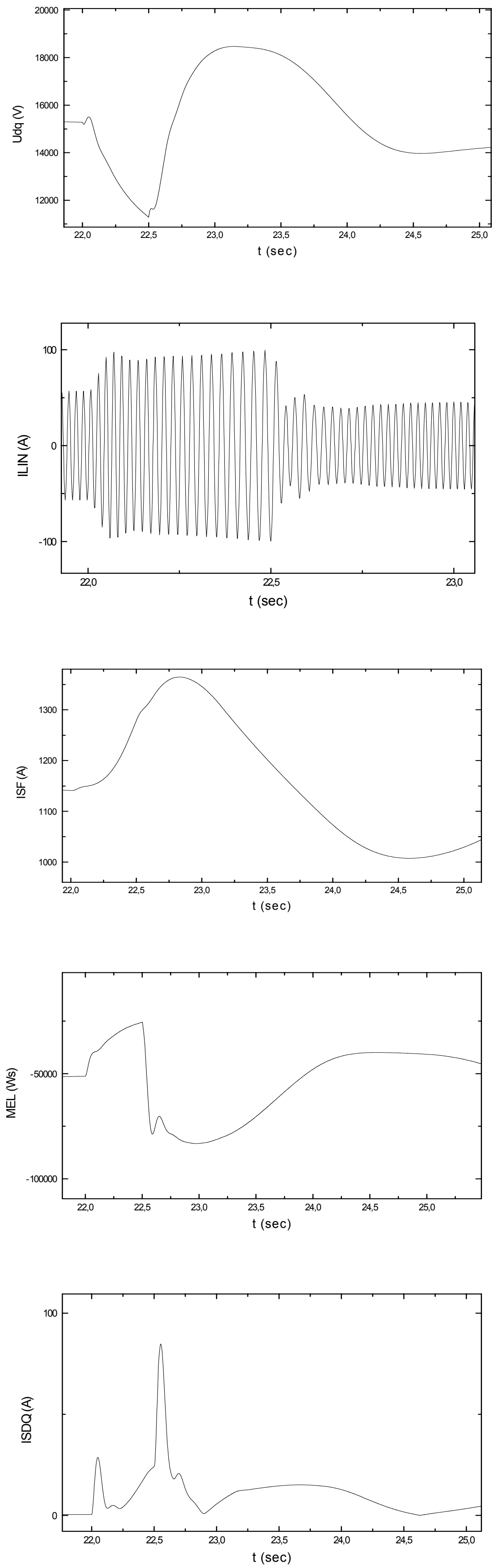
Generally, its obvious that in the initial time after the interruption of the diesel machine' s operation the system's variables deviation are stronger in comparison to the deviation of the case of 1 MW WECS connection to the weak energy grid and in comparison to the deviation of the variables via a short cirquit at the excitation of the synchronous generator for 0,5 sec, respectively.











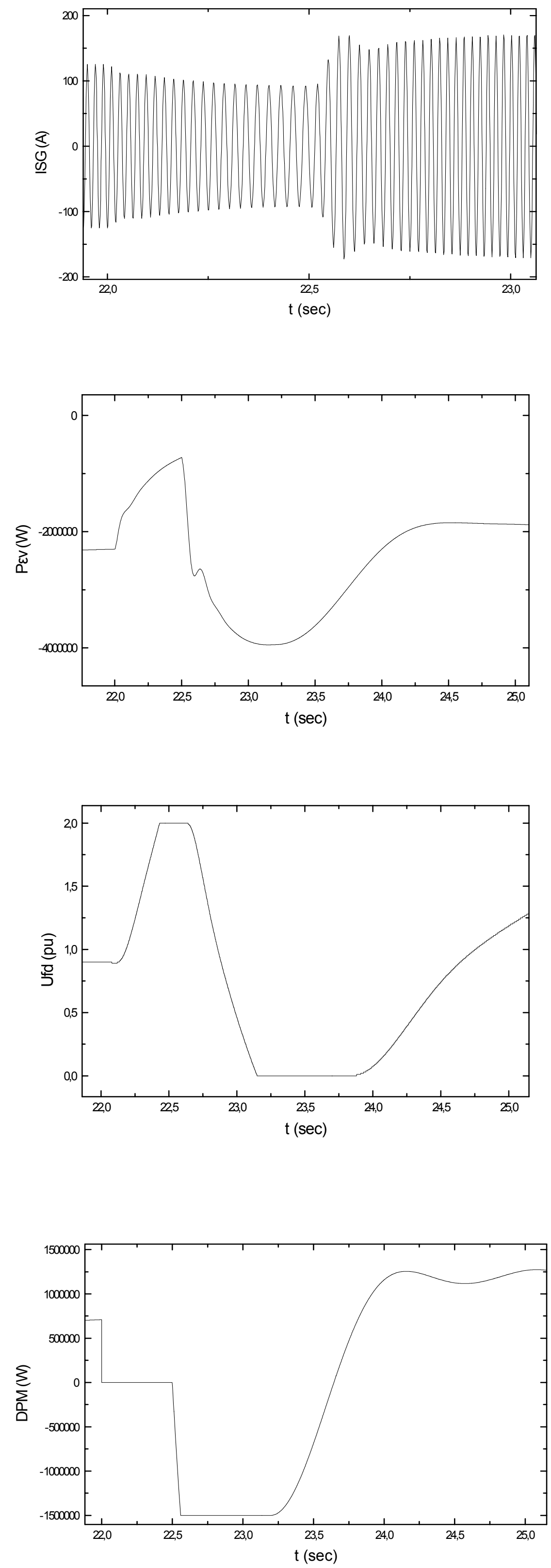
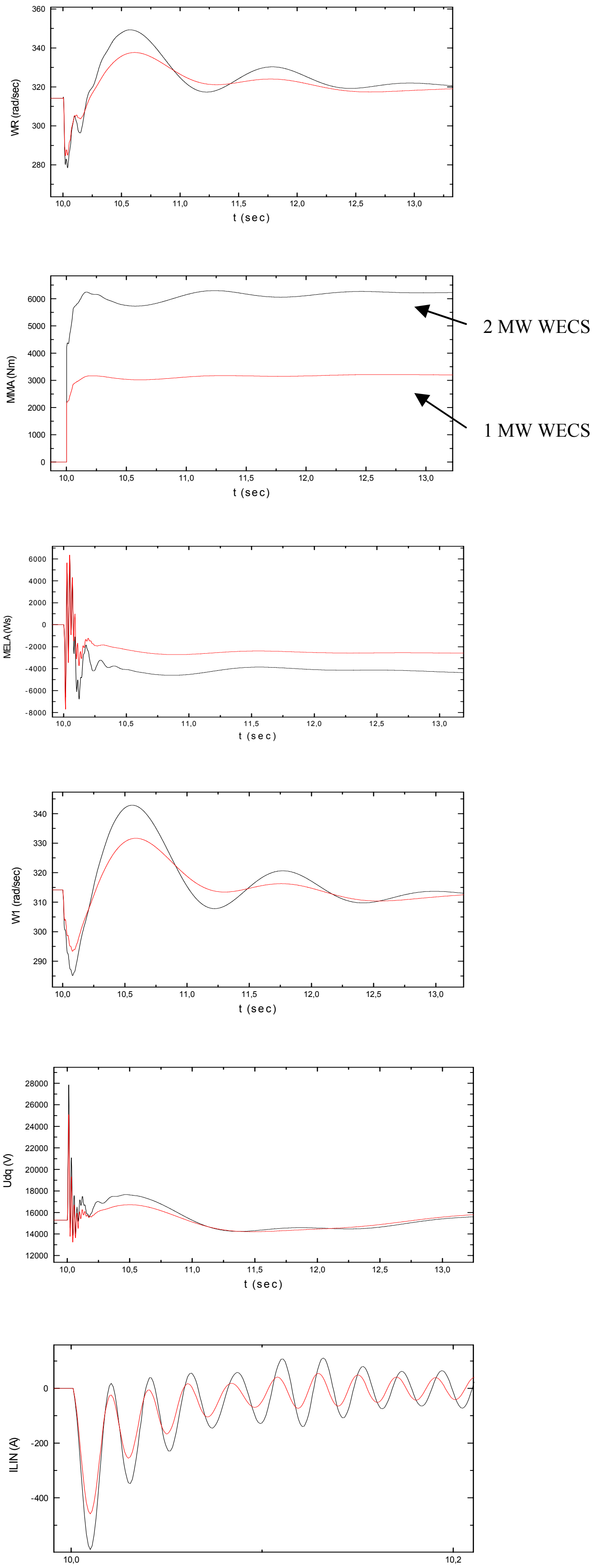


Fig. 2: Variables deviation at the interruption of the diesel machine's operation for 0,5 sec for 1 MW WECS connection.



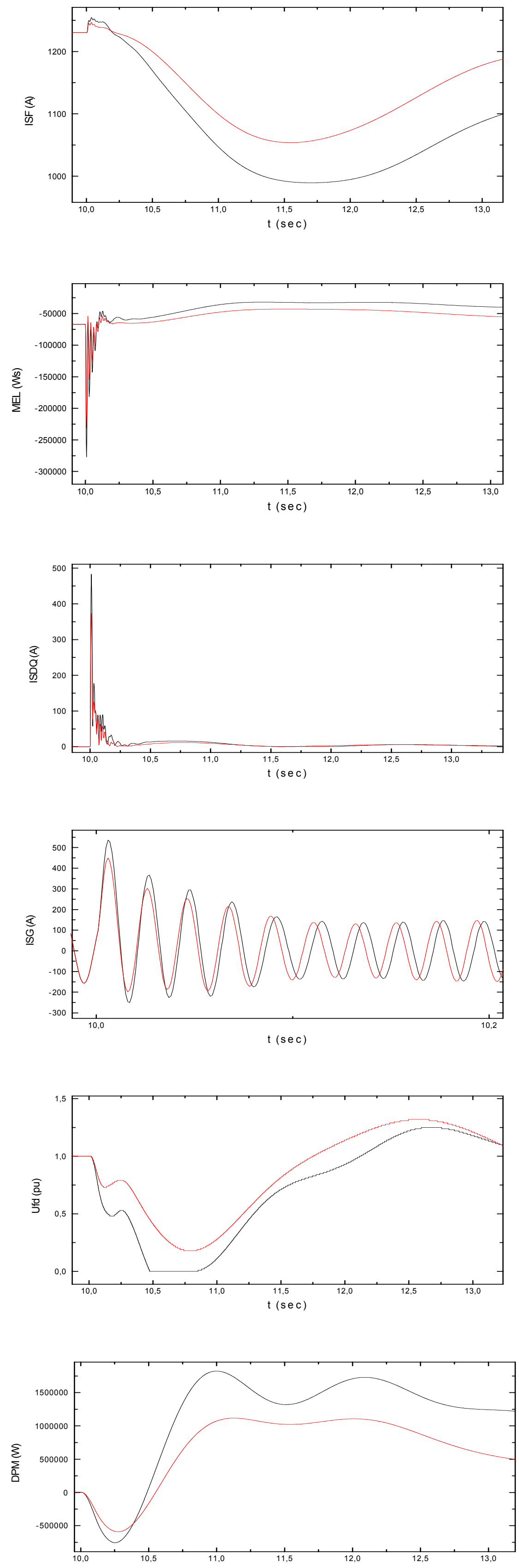


Fig. 3: Comparison of the variables deviation at the connection of 1 MW & 2 MW WECS (V_w=12 m/s).

4. CONCLUSION

The comparison of the weak energy grid's variables for two characteristic cases a) WECS connection to the weak energy grid and b) the interruption of the diesel machines operation for a duration of 0,5 sec, takes place in this paper. A computer based simulation model, offers the possibility to study any transient operation that involves the whole power system. Via the simulation results, we can see that in the case which we have an interruption of the diesel machine's operation the system variables deviation are strongly enough in comparison with the connection of same WECS to the weak power grid. If the fault duration is bigger 0,5 sec, the system cannot become to a new steady state operation.

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NOMECLATURE

u_{WIND}: wind velocity,
u_{WN}: nominal velocity (= 12m/sec)
C_M: torque coefficient
C_P: power coefficient
λ: tip speed ratio
R: wind turbine blade radius (= 23.708 m)
K_A : ratio of the velocity converter (= 127.24)
M_{MA}: mechanical torque on the axis of the A.G.
M_{ELA}: electromagnetic torque of the A.G.
(I_{AGS}): stator current matrix (a-b-c- axis) of the A.G.
(I_{AGR}): rotor current matrix (a-b-c- axis) of the A.G.
M_{EL}: electromagnetic torque of the S.G.
(I_{SFT}): rotor current matrix (d-q- axis) of the S.G.
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)
Js: inertia of diesel engine and S.G. (= 1000 $Wsec^{-3}$)
U_{FN}: nominal excitation voltage (= 75V)
P_{NA}: nominal power of A.G. (= 1000 kVA)
U_{NA}: nominal voltage of A.G. (= 6 kV)
$\cos\varphi_N$: nominal power factor of A.G. (= 0,9)
n_{NAG}: nominal rotation speed of AG (= 3096 rpm)
p_A: pair pole number of AG (=1)
ω_1: angular velocity of S.G., ω_R: angular velocity of A.G.
Ω_{WM}: angular velocity of the wind motor
J_A: inertia of wind turbine and A.G. (= 10 $Wsec^{-3}$)
P_{mo}: initial value of mechanical power of S.G. (= 3000 kVA)
D_{PM}: deviation of the mechanical power of the S.G.
U_{ref}: AVR reference voltage, U_{fd}: excitation voltage (p.u.)
V_t: S.G. terminal voltage (p.u.), $V_{dq} = \sqrt{(V_d^2+V_q^2)}$
α: inclination of the WECS landscape axes and of the blades
β: changing of the ratio of the velocity converter

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,
Parameters of the load, line and transformer:
R_{LOAD}= 80.974 Ω, L_{LOAD} = 0.1248 Ωs R_{LIN} = 0.2381Ω/km, L_{LIN} = 0.00107 Ωs/km, DL = D_{LIN} = 5 km, R_{TR}= 1.41 Ω, L_{TR} = 0.0428 Ωs, TR= 2.55
Parameters of S.G. voltage and frequency controller:
T_C= 0.015 s, T_S= 1.0 s, time constant of control mechanism and diesel - S.G., R=-2 10^{-5} 1/kW, diesel permanent speed droop, K_I =-1.5 10^5, K_D= -1.0, gains of integral-differential controller
K_A= 50, K_E= 1.0, K_F= 0.08, K_R= 1.0: *gain of amplifier, excitation and stabilizing loop*
T_A= 0.05 s, T_E= 0.5 s, T_F= 0.35 s, T_R= 0.06 s : *time constant of amplifier, excitation, stabilizing loop and delay of control mechanism, respectively.*
K_{AN}= 0.1, T_{AN}= 0.1 s, K_{AS}= 0.1, T_{AS}= 0.1 s, *time constant and delay of control mechanism of the wind motor*.
Parameters of asynchronous generator (1 MW):
R_{sA}= 0.20Ω, R_{RA}= 0.776 Ω, L_{SA}= 0.2 Ωs, L_{RA}= 0.195 Ωs, L_{S0A}= 0.0 Ωs, L_{R0A}= 0.05 Ωs, L_{HA} = 0.19 Ωs.