An Approach to Selection of Basic Parameters Relevant for Automatic Reclosing Technique in Electric Power Systems

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Abstract: - The paper presents research results of the influence of automatic reclosing control in electromagnetic power line networks (rated voltage: 110 kV, 220kV and 400 kV) on the choice of hydrogenerator basic parameters with regard to their mechanical dimensioning.

Key-Words: - hydrogenerator, electromagnetic power line, automatic switching control

1 Introduction

On general, synchronous generators are machines for electromechanical energy conversion (conversion of mechanical energy into electrical) and they are main electrical energy producers in each electric power system.

Each generator should be electrically and mechanically designed so as to prevent any major damages (stator winding, shafts and frames) in case the most dangerous failures (e.g. short circuits) occur. Synchronous generators with salient poles are parts of aggregate in hydroelectric power plants, and because of their dynamic characteristics (the problem of surge unloading etc.) it is very important to approach mechanical calculation of synchronous generators with salient poles with great attention.

So far, mechanical calculations of synchronous generators with salient poles regarding the so-called electrical influence have been based on electromagnetic element analysis which may occur during three-pole short circuit on their terminals.

However, the development of synchronous generators theory pointed out two-pole short circuit "intensity" when its higher value is considered rather than during three-pole short circuit and especially if it occurs when phase shift on generator and network terminals is 2,1 rad/s and 120º el, respectively.

2 Basic Parameters of Synchronous Generators with Salient Poles

The choice of synchronous generators with poles its size (strength) is considered depends on the hydroelectric power plant into which be generator is built in (driving machine: Pelton, Francis, Kaplan – vertical design or tube/pipe turbine). It is necessary to specify the following items when a synchronous generator is offered:

- power in MVA,
- rotation rated speed in min^{-1},
- rated voltage in kV and voltage control range,
- frequency in Hz
- power factor $\cos\varphi_n$,
- design,
- cooling system,
- type (sort) of excitation system and
- moment of inertia $_{sg}(\text{tm}^2)$.

Each synchronous generator due to its driving machine "has" its so-called natural parameters. Parameter deviations occur according to the investor's requirements and they influence both the design and the price of the generator.

3 Conditions and Driving of Synchronous Generator with Salient Poles

Each synchronous generator may be in so-called quasi-stationary drive (drive within power system or island drive) or in transient condition drive.

Quasi-stationary drive of a generator is characterized by the fact that driving machine moment and electromagnetic moment are the same. In other words, according to its static driving diagram all values characterizing its condition are almost unchanged for a specific driving point.

Transient conditions in synchronous generators occur due to the following known patterns:

- different electromagnetic stationary conditions have different total amounts of magnetic energy accumulated in the generator. Magnetic energy cannot be changed abruptly, that's why electromagnetic transient phenomena occur,
- different mechanical stationary conditions have different kinetic energies. Kinetic energy cannot be changed abruptly, that's why mechanical transient phenomena occur. Some phenomena may be observed, taking into consideration constant rotation speed, as electromagnetic transient phenomena much "faster" than mechanical (e.g. "surge" three-pole short circuit). Likewise, certain mechanical phenomena may be defined relatively slow, so that during their development there is no electromagnetic influence (e.g. asynchronous run of synchronous generator). The amounts of the biggest amounts of synchronous generator with salient pole surge electromagnetic moments may be, in case of short circuits, calculated in the following way [1]:

$$M_{uelmK2s\max} = \frac{3}{2} \cdot \frac{\sqrt{3} U_f^2}{\left(x_d'' + x_i\right)} \qquad (1)$$

$$M_{uelmK3s\max} = \frac{U_f^2}{x_d''} \qquad (2)$$

where U_f stands for phase voltage, x_d'' is starting synchronous reactance in axe d, x_i stands for inverse reactance, while r.j. represents relative unit). The above expressions point to two synchronous parameters only (x_d'' and x_i) which have been determined by the design requirements, while phase rated voltage greatly depends on generator rated power. In other words, according to [1] zero reactance occurs between (1/6 to 3/4) x_d''.

Considering the usual assumption that $x_d'' \approx x_q''$ the condition with regard to mechanical stress of generator winding is almost the same as the situation in which surge three-phase short circuit occurs. The relationship between surge currents amount during "three-pole, two-pole and one-pole surge short circuit 1 : √3/2, (≤1).

Researching the phenomena due to one-pole short circuit does not reveal any new findings considering condition during two-pole short circuit, i.e. instead of taking inverse reactance $\sqrt{x_d'' x_q''}$, reactance ($\sqrt{x_0''} + \sqrt{x_d'' x_q''}$) should be taken. According to [1] and taking into consideration the least favorable case of highest possible electromagnetic moment in generator air gap during three-pole, two-pole ($v_0 = 90°$) and one-pole short circuit ($v_0 = 0°$) and for the case of approximately symmetrical generator ($x_d'' \approx x_q''$) and assuming that $x_0 = 0{,}5\ x_d''$, shows that the two-pole short circuit is the most dangerous.

4 Power Plant and Power System Interaction

Each electric power plant in electric power supply system is connected in one of its junction points of specified voltage level. Junction points are, for example, busses in electric power plants connected with other system elements by means of overhead or underground cables. Therefore, it may be said that the point of so-called quasi stationary or transient interaction between the power plant and its aggregates and the rest of the power system is the point where it is connected to the system. It is usually called power plant threshold.

However, the practice shows that so-called temporary or transient failures - disturbances - on lines which "come out" of the power plant may have a great influence on electromechanical resistance of their aggregates as well as on their adequate dimensioning. In other words, in order to preserve the stability of electric power plant system due to such failures, automatic switching control technique on lines is used. In practice three-pole and two-pole automatic switching control is applied. It was noticed that when automatic switching control on lines near generators is applied, surge current and electromagnetic moment of the generator are much higher than during three-pole surge short circuit. This is understandable because the generator connects to the network again without voltage amount and frequency control (differences) and generator and network and without angle amount control between generator voltage vector and network. With regard to automatic switching control technique, two parameters are essential:

- T_{Kr} → failure time and
- T_{bn} → no voltage break time

Parameter T_{Kr} determines its own time of protection device (relay) and the particular switching off time which is very difficult to be influenced.
Parameter T_{bn} is possible to be changed, but the limits are very restricted (it is usually between 300 ms and 700 ms). Values below 300 ms (for example: change to 200 ms) [2] influence the switch, while values above 700 ms influence the problem of generator transient stability.
Usual values for T_{bn} in Croatian transmission network are: for three-pole automatic switching control APU (300 ms) and for one-pole APU (500 ms).
Similarly, while analyzing three-pole electromagnetic moment of synchronous generator, when a "close" three-pole APU operates, the following parameters should be considered:

- voltage after leakage synchronous reactance,
- time constants (T_{d0}', T_d' and T_d''),
- aggregate moment of inertia, J and driving-wheel mass mD_Σ^2, respectively.

It is obvious, that leakage reactance, time constants and driving-wheel mass are in connection with generator design [3].
Higher voltage after leakage reactance as well as greater driving-wheel masses contribute to decreasing of moments which could occur during APU technique application.

5 Relationship Between Hydroelectric Power Plant and Power System with Mechanic Calculation of Shaft of Synchornous Generator with Salient Poles

The interaction between any hydroelectric power plant regardless its type (kind) and size and electric power system is dynamic. It is essential that synchronous generator, as well as other elements (turbine, bearings, aggregate foundation) are mechanically designed so that, expected disturbances in the system as well as in the aggregate itself do not cause failure. When "turbine + synchronous generator" is dealt with, it is the question of electromechanical assembly where both mechanical and electrical characteristics of the environment (electric power plant) should be taken into consideration, particularly those characteristics that influence the design of the assembly with the regard to its reliability and availability. This is very important when parameters are being chosen either for new plants or for renewing old ones especially when we have in mind their operation in the conditions of electric energy open market, (electric energy power system - horizontal structures).

In earlier approaches to mechanical dimensioning of a synchronous generator with salient poles the starting point was the assumption of short circuit occurring at its terminals. The generated and developed electromagnetic moment is transferred to the shaft, bearings and the foundation via air gap. The amount of the above moment is essential, in the first place, for mechanical dimensioning of the shaft and aggregate foundations.
However, according to [4] it was stated that in the most unfavorable case, the two-pole short circuit is "more dangerous" on terminals of synchronous generator with salient poles than the three-pole short circuit. It is 1.8 times more dangerous. If winding resistance is taken into consideration, it is necessary to take into consideration additional choke moments in the first-half period of transient phenomena as well. In the case of junctions with choked winding the influence is "summing" in the amount of about 10%, while with machines without choked winding such influence is negligible. According to [5] when dimensioning aggregate foundation with synchronous generators with salient poles the calculation is done with the moment during two-pole short circuit as follows:

$$M_{KS2} = M_T\left(1+\frac{J_1}{J_1+J_2}\right)\left(A_1 - A_2 - A_3\right) \quad (3)$$

where the coefficients:

$$A_1 = \alpha_0\left(1-\cos\omega_1 t\right)$$

$$A_2 = \left(\frac{\omega}{\omega_1}\cdot\frac{\alpha_1}{1-\left(\frac{\omega}{\omega_1}\right)^2} + \frac{2\omega}{\omega_1}\cdot\frac{\alpha_2}{1-\left(\frac{2\omega}{\omega_1}\right)^2}\right)\cdot\sin\omega t$$

$$A_3 = \frac{\alpha_1}{1-\left(\frac{\omega}{\omega_1}\right)^2}\cdot\sin\omega t + \frac{\alpha_2}{1-\left(\frac{2\omega}{\omega_1}\right)^2}\cdot\sin^2\omega t$$

The relationship J_1 / $(J_1 + J_2)$ compares turbine operating wheel moment of inertia and total aggregate moment (J_2 is synchronous generator with salient poles moment of inertia). For hydrogenerators with vertical or pipe design (Kaplan - propeller), and according to [5] with regard to shaft stress problem, J_1 / J_2 relationship is essential. It is usually between 0.02 and 0.15.
In the same way, [6] based on "Litostroj" - Republic Slovenia, Ljubljana experience and information gives an estimate that $m_{RK}D_{TK}^2$ (Kaplan turbine) 5% to 10% required value for synchronous generator, and for pipe

design $m_{RC}D_{RC}^2$ about 20%. This corresponds to values according to [5]
Therefore, based on the above relationship $J_1 / (J_1 + J_2)$ may be within limits 0,0196 to 0,166. A more detailed research results, for example a definite hydroelectric power plant with pipe turbines can be seen in [3].
In order to get an insight into electromagnetic moment relative values (M_{KS2}/M_T) versus equation (3), as well as for different values of own frequency ω_1, power unit axis swinging [ω_1 = 31,4159 rad/s (5 Hz); 62,8318 rad/s (10 Hz); 94,2478 rad/s (15 Hz); 125,6637 rad/s (20 Hz); 157,0796 rad/s (25 Hz); 188,4955 rad/s (30 Hz); 219,9115 rad/s (35 Hz); 251,3274 rad/s (40 Hz) i 828,7433 rad/s (45 Hz)], and using EXCELL program the results given in Fig. 1. to Fig. 3. have been obtained.
Coefficients α_0, α_1, α_2 [5] are dependent on generator active resistances τ_1 and $\tau 2$, initial x_d'' and inverse reactance of the generator, x_2, rated angle speed of the power unit, ω_n is 314,1592 rad/s (50 Hz), and the relationship $J_1 / (J_1+J_2)$ = 0,0196. In the case of relationship border value 0,166, values app. 8 times greater are obtained.
Observing time scale is 0 to 0,5 s because during two pole short circuit on synchronous generator terminals electrical protection - mostly differential - acts within 0,1 s.

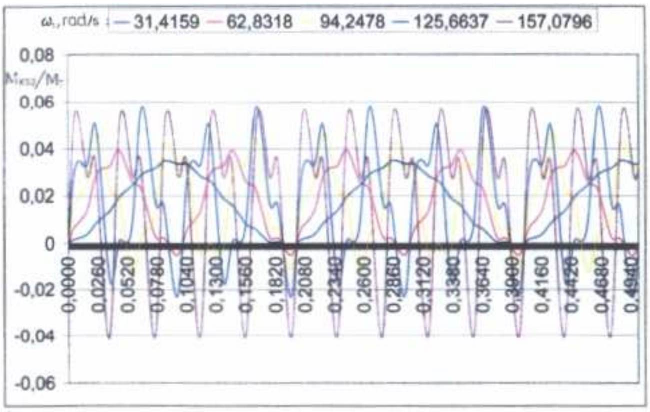

Fig. 1. Time period of synchronous generator with salient poles relative values during two pole short circuit on its terminals and own frequencies of power unit axes, (5 to 25) Hz $J_1/(J_1+J_2) = 0{,}0196$

Amounts of relative electromagnetic moments in synchronous generators with salient poles according to Fig. 1. to Fig. 3. while monitored up to 0,5 s, seemed to be highly dependable on their axis own frequency, ω_1. At lower ω_1 values, i.e. from 0 to 251,3274 rad/s (that is 0 Hz to 40 Hz), the amounts do not exceed values higher than 2.0 p.u. (this refers to the bigger relationship value $J_1 / (J_1 + J_2)$ = 0,0196, i.e. 8 times bigger value than the same amount relationship, 0,0196 according to Fig. 2.).

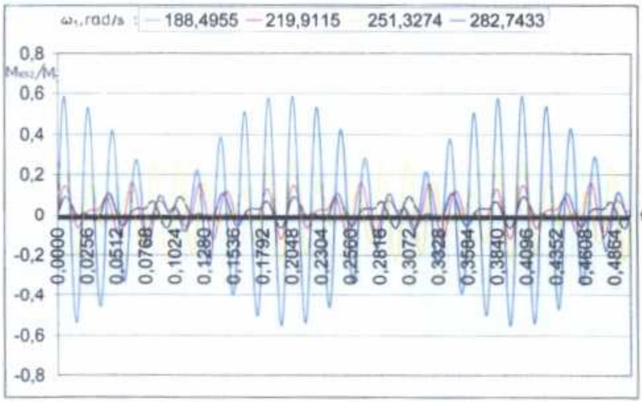

Fig. 2. Time period of synchronous generator with salient poles relative values during two pole short circuit on its terminals and own frequencies of power unit axes, (30 to 45) Hz $J_1/(J_1+J_2) = 0{,}0196$

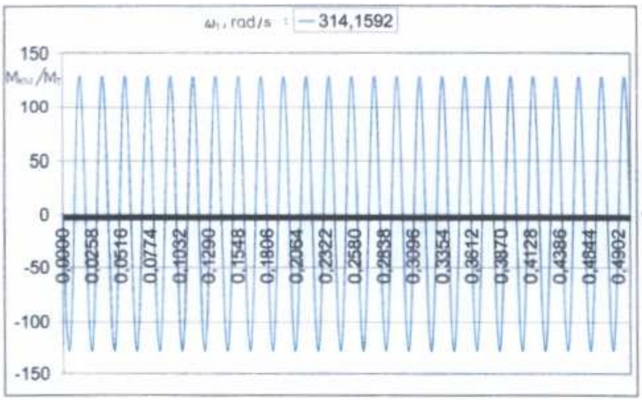

Fig. 3. Time period of synchronous generator with salient poles relative values during two pole short circuit on its terminals and own frequencies of power unit axes, (100) Hz $J_1/(J_1+J_2) = 0{,}0196$

However, according to the Fig. 2., and for the frequency ω_1 = 282,7433 rad/s (45 Hz suits fine), the highest value is app. 4,8 p.u.
In resonance frequency conditions $\omega_n = \omega_1$ (Fig. 3.), the status is completely clear, understandable and prohibited, of course, so it is possible to claim that power unit axis own frequency should be lower than at least 282,7433 rad/s (45 Hz).
At the own frequency, ω_1 higher than 314,1592 rad/s and 628,3184 rad/s (100 Hz) Fig. 3. it can be seen that at ω_1 = 628,3184 rad/s considerable increase of electromagnetic moment occurs in the monitored time, and it is quite obvious that it should not be allowed.

6 Conclusion

The knowledge of possible reasons for automatic switching technique application on transmission lines have an essential influence on mechanical dimensioning of synchronous generators in hydroelectric power plants.

On the contrary, not knowing the above reasons has already led to damages on hydro aggregates not only in our power system (HEPP "Cakovec" for example) but elsewhere as well (Russia for example). It is evident that the subject requires a high degree of co-operation between different expert groups, co-ordination of all experts taking part in the process of planning, designing, building, putting into operation and monitoring the process of both new and revitalized hydroelectric power plants.

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