Issues above Asynchronous Generator’s Excitation in Wind Aggregates

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Abstract—The paper presents some considerations regarding the problematic of asynchronous generator’s (AG) excitation. There are presented some theoretical considerations regarding the efficiency of the capacitive excited asynchronous generator compounding regarding the load voltage variation compensation. There is presented the determination of the compounding condenser’s capacity by using the graph-analytical method and respectively the calculation of the compound condenser excited induction generator characteristics even in the case of low speed AG. The above method can be applied in the case of energy power stations such as wind aggregates connected to the power grid.

I. INTRODUCTION

Actually, the domain of power energetic has to address and solve major issues such as: the attenuation of the industry’s destructive influence over the natural environment; to equal the speedy evolution of the energy demand (expected to be doubled in the next few years) and others related.

Renewable energy resources exploit naturally occurring energy processes (solar, water and wind resources).

The above stated issues can be fulfilled only by increasing the utilization efficiency of energy resources by new methods and techniques.

In the case of wind energy domain, the operations at variable rotation speed represents a major desiderate [1].

The issues of functioning of energetically groups at variable controlled rotation speed could be solved by using the asynchronous generator (double feed induction machine, induction machine cascades, etc.).

However, in the case of isolated power grids, the asynchronous generator usage is less represented due to some technical issues such as the low quality of the delivered energy [1] [2].

The functioning regime of asynchronous machines as a generator, parallel to a constant frequency and voltage grid, is generally well described in the technical literature.

The motor operating regime presents the same mathematical models, the equivalent circuit, the circular diagram, etc., the difference being only the slip value, positive for motor and negative for generator regime. This functioning regime and its characteristics are very well known, the present paper illustrates only the peculiarities that can be noticed in the case of generator regime and some possible solutions for solving the problems occurred in the exploitation of the wind aggregates equipped with asynchronous generators.

II. COMPOUND EXCITED INDUCTION GENERATORS – CONSIDERATIONS

The theoretical considerations proved by the experiments performed on test rigs, validate the effectiveness of capacitive excited induction generator compounding regarding issue of load voltage variation compensation [1].

The induction generator compounding, by analogy of d.c. generator compounding, consists in the use of serial condensers $C_s$ complementary to a shunt exciting condensers $C_d$ (as presented in Figure 1).

The phase-modifying effect of the serial condensers is explained by the fact that the load voltage is equal to vector sum of the generator voltage $U_G$ and of the compounding condensers voltage $(U)_{C_s}$.

![Figure 1. Schematic diagram of compound induction generator power circuit.](image)

III. METHOD FOR ESTABLISHING THE CONDENSERS VALUES USED FOR EXCITATION OF THE ASYNCHRONOUS MACHINE

There is used the characteristic family $U = f_k(I)$ represented in relative units $U/U_0 = f_k(I/I_N)$, for different values of the power factor $(\cos \varphi)_k = \text{constant}$, considered as parameter, analytically calculated or experimentally determined. In Fig. 2 there are depicted
the characteristics of an case study induction generator, given in [7], \( U_f = 150 \text{ V} \), \( I_N = 2.48 \text{ A} \), at \( C_d = 84 \mu \text{F} \) and different values of the power factor \( \cos \varphi_k \) = const.

For a given value of current \( I = \text{const.} \) and different values of the power factor \( \cos \varphi \), from the external characteristics family \( C = \text{const.} \), there can be determined the voltage values. Considering the computed voltage values at different \( \cos \varphi \) there can be represented the hodograph \( U_G = f(\cos \varphi) \), for \( I = 50\% \) as depicted in Figure 2.

Equivalent to the above considerations, there are pursued the steps:

i). There is figured out the imposed voltage phasor \( \overline{U}_S \) at the compulsory current and power factor \( \cos \varphi \)

ii). There is drawn the vector \( (\overline{U})_{C_S} \) direction and sense knowing that it is in advance with 90°, related to the current phasor \( \overline{I} \).

iii). Considering that the phasor \( (\overline{U})_{C_S} \) has the extremity of phasor \( (\overline{U})_{C_S} \) and, at the same time, the extremity of \( (\overline{U})_G \) is on the hodograph \( \overline{U}_G = f(\cos \varphi) \), results that the extremity of \( (\overline{U})_G \) shall be at the intersection of phasor \( (\overline{U})_{C_S} \) direction with the hodograph, the point of intersection being the only one for which the above mentioned conditions are fulfilled. Also, taking into account the voltage \( (\overline{U})_{C_S} \) on the condenser \( C_S \) and the current \( I_{C_S} = I_C = I_k \), corresponding to the considered operating condition, for which the compensation condenser capacity is determined, there can be calculated the required capacity value.

\[
C_S = \frac{I_k}{\omega (\overline{U})_{C_S}} \tag{1}
\]

In the examined case in [1] the \( C_S \) voltage has resulted

\[
(U)_{C_S} = a_d a_4 = 55.3\% U_f = 53.5\% U_S \quad (2)
\]

In the considered functioning regime, the current is \( I = I_N = 2.48 \text{ A} \), and according to (2) it results \( C_S = 107\mu\text{F} \). It can be noted that \( C_S > C_d \).

The calculus method of the load voltage \( U_S \), for different values of the load current, consists, according to relation

\[
\overline{U}_S = \overline{U}_G - (\overline{U})_{C_S}, \tag{3}
\]

in seeking a phasor \( \overline{U}_S \) that satisfies the relation (3) and in which \( (\overline{U})_{C_S} = \frac{I_k}{\omega C_S} \) (computed proportionally with the ratio between \( I \) and \( I_N \) for which was calculated \( C_S \)), the phasor \( \overline{U}_S \) direction is known (imposed by the considered \( \cos \varphi_S \)) and the extremity of \( \overline{U}_S \) coincides with the extremity of \( (\overline{U})_G \) and thus it must be on its hodograph for the considered \( I_k \) value of the current. The construction is shown in Figure 3.

There were determined the values of voltages \( U_S, U_G \), \( (\overline{U})_{C_S} \) corresponding to different values of the current, for a small power induction generator. Considering the resulted data there have been built the characteristics \( U, U_G, (\overline{U})_{C_S} = f(I) \). There can be noted that the compounding performed by instrument of static condensers is an efficient proceeding of compensation.

There is mentioned the method’s efficiency even in case of sudden variations of inductive loads [1].

Examining the influence of the load power factor, there is mentioned that in case of \( \cos \varphi < 1 \), the compounding is more efficient than in case of active load. Therefore in case of generator considered in [1], for a load with \( \cos \varphi_S = 0.91 \) there can be noted an error up to 3%, while for pure resistive load (\( \cos \varphi_S = 1 \)) there result compensating errors up to 8% [3] [4] [5].

In [1], [7] in order to reduce the compounding condenser capacity and, correspondingly their costs and dimensions, there is also discussed the possibility of compounding condenser connection by means of some step-down current transformers.
IV. COMPOUND CONDENSER EXCITED ASYNCHRONOUS GENERATOR

The grapho-analytical above exposed method of the compound induction generator characteristics is quite difficult. The variation of induction generator parameters $x_s, x_m, r_m$ are due to the frequency variation with the load or the rotation speed and/or the parameters $x_m, r_m$.

For a given load $S$ power factor, that is for a constant ratio $R_s / X_s$ there will be considered $N$ values of the active and reactive resistances of the load

\[
R_s = (N - k + 1)(R_s)_N
\]

\[
(X_s)_{fs} = (N - k + 1)(X_s)_N f_s
\]

Where $k=1,2,\ldots,N$

Therefore, for each value of the parameter $k$, the unknown variables $s$ (slip) and $U$ (voltage) will be found as solutions of currents’ equilibrium equation:

\[
\frac{I_{s}}{C_{s}} S_{s} = [R_s j(X_s - 1/\omega C_s)]
\]

\[
\bar{I}_{c,s} = U / Z_{c,s} = U[R_s j(X_s - 1/\omega C_s)] / R_s^2 + (X_s - 1/\omega C_s)^2
\]

Considering (8), (9) the equations (10), (11) will have the expressions

\[
ABS I_{ag} = ABS \frac{UR_s}{R_s^2 + (X_s f_s)^2 - 1 - s / 2 \pi \cdot f_s \cdot C_s}
\]

The active and reactive components of the current $I_{c,s}$ will be calculated with the following relation:

\[
Z_{c,s} = R_s + j(X_s - 1/\omega C_s)
\]

\[
\bar{I}_{c,s} = U / Z_{c,s} = U[R_s j(X_s - 1/\omega C_s)] / R_s^2 + (X_s - 1/\omega C_s)^2
\]

\[
(I_s)_{c,s} = UR_s / (R_s^2 + (X_s - 1/\omega C_s)^2)
\]

Considering the slip value $s$ for which equation (12) is satisfied, the solution search will continue at other value of the voltage. In accordance with the divided interval method, each time the previous value of the voltage divides the previous interval into two parts. At the next step will be considered and divided the part-

i) Smaller values of $s$, in the case when $I_{aG} > I_{aS}$, then $s = (s_k + s_{min}) / 2$.

ii) Greater values of $s$, in the case when $I_{aG} < I_{aS}$, then $s = (s_k + s_{max}) / 2$.

The calculation diagram is based on above exposed algorithm and was implemented in Matlab Simulink software environment.

Estimating an admissible variation of the frequency from the standard at unload operation the frequency value, may be accepted

\[
f = f_N \pm \Delta f
\]

The rotation speed that may assure at unload operation this frequency will be the following:

\[
n = f_0 / p = (f_N + \Delta f) / p
\]

Considering the equivalent scheme at no-load operation, that is at $s = 0$, we’ll have

\[
I_C = (I_G)_0
\]

Where

\[
I_C = U_0 / X_c = U_0 \cdot C = U_0 \cdot 2 \pi \cdot f_0 \cdot C
\]

and

\[
(I_G)_0 = U_0 / \sqrt{(r_i + r_m)^2 + (x_i + x_m)^2} \equiv U_0 / (x_i + x_m)
\]

Having in view the above relations, we’ll obtain

\[
U_0 \cdot 2 \pi \cdot f_0 \cdot C = U_0 / (x_i + x_m)
\]

Where from

\[
C = 1 / 2 \pi \cdot f_0 \cdot (x_i + x_m) = \ldots = f_N / 2 \pi \cdot (f_N + \Delta f) \cdot (x_i + x_m)
\]

The condenser capacitance $C_s$ may be found considering successively different values of it and calculating each time the external characteristics $U_s = \bar{f}(s)$.

The required value of $C_s$ will be that which assures an acceptable external characteristic [1] [6] [8].
V. ISSUES ABOVE LOW SPEED ASYNCHRONOUS GENERATOR EXCITATION

It is known the nowadays trend to use low speed generators for wind aggregates. Generally, permanent magnet synchronous generators coupled directly to wind turbines are considered.

However, asynchronous generators are justifiable even for low speeds because of their advantages in simplicity, cost, and control opportunity. The autonomous induction generators, however, have an important reactive power $Q$ relative to machine rated power $P_N$. For example: $4.43P_N$, at 1 kW, 250 RPM; or $3.71P_N$, at 2.5 kW, 250 RPM, etc [1] [7] [9].

The excitation reactive power of a small power and small speed machine is relatively large. However, these machines are constructed using the existing technologies without considering the possibility of optimization by choosing alternative machine dimensions and technologies.

In view of the above considerations and due to the fact that the reactive power is involved in excitation, and additionally it affects the power required and cost of the voltage control system it is important to clarify whether it is possible or not to improve the power factor values of low speed asynchronous generators by reducing the excitation reactive power of these machines. This question rises naturally for induction machines with large number of poles.

It is known that the excitation reactive power $Q$ of autonomous induction generator consists of a constant part $Q_0$, independent of the load, and a varying part $AQ$, which varies with the load. The varying reactive power $AQ$ is submitted to the excitation control system and determines the size and cost of that system.

Using an autonomous induction generator equivalent scheme and proper computer programs, it is possible to determine the working characteristics of the generator for different regimes (n=const, n-controlled, etc.) and different loads, and hence the reactive excitation power and its components $Q_0$ and $AQ$ [1] [9].

VI. CONCLUSIONS

There certainly exists the technical - economic basis to a large scale introduction of asynchronous generators in wind energy conversion systems and mixed systems.

The theoretical and experimental studies performed permit the setting up of technical conditions necessary for a normal operation of an asynchronous generator in power energy stations.

There is presented a graph-analytical method for the determination of the compounding condenser’s capacity and respectively the calculation of the compound condenser excited induction generator characteristics.

There are also presented considerations regarding the excitation of low speed asynchronous generators. The low speed machines present an advantage for wind energy conversion system due to the fact that they allow a direct coupling of the wind turbine with the electrical generator without using a gear-box and therefore they are more reliable than classic asynchronous generators.

There can be drawn the conclusion that the theoretical considerations and experiments confirm the efficiency of the capacitive excited induction generator compounding regarding the issue of load voltage variation compensation.

Also, the new technological advances in field of electronic power devices and control engineering science permit a more facile integration of asynchronous generator in power energy generating facilities.

REFERENCES