Reconditioning in synchronous operation with one parallel induction generator

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***Abstract*—The purpose of this paper is to compare mathematical modeling and practical bench in order to validate the electrical interactions between an induction generator and a synchronous generator. Two generators was connected to a common bus in steady state, subject to non-linear load. The results comparing modeling and bench tests show that the induction generator besides the active power increasing, has a better way for harmonic currents flowing in common bus. It was concluded that the induction generator repowering and attenuates current harmonic components present at the connection point, improving the network voltage profile.**

***Index Terms*—Repowering, Induction Generator, Synchronous Generator, Harmonics.**

I. INTRODUCTION

Repowering hydroelectric power plants has been increasing the power generated. Since there is spare capacity of turbine power and that is not being exploited by the generator already installed, it can be repowered. There are three possible ways to repowering: i) replacing the synchronous generator for a bigger one; ii) adding a second synchronous generator through double coupling on the turbine shaft; iii) adding a second generator coupled to the turbine shaft, but in this case an induction generator.

The induction generator is a viable technical and economical option to power generation [1]. The induction generator is used in electrical power plants repowering therefore has a low cost, is more robust, has simple construction, lower cost and less maintenance when compared to a synchronous machine. As disadvantage, external resources are required to compensate reactive power. On repowering, smaller induction generator is connected on a common bus to a larger synchronous generator and thus induction generator may have its reactive power compensated by synchronous generator, without power factor losses in the coupling point between them and can be dispensed of the control voltage, as this will be determined by system [2].

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The induction generator besides low maintenance, does not require DC excitation and synchronization. In machines parallel operation is necessary to use of motorized thermomagnetic circuit breakers and in the case of induction generators, where the synchronization is not required, it reduces the cost of the circuit breaker [3]. In the distribution system the impact of induction generators connection is studied in [4]. To stabilize reactive field, the induction generator needs to reactive power on system input. The system supplies this reactive power, affecting losses and system voltage drops. The results show the relationship between losses due to change of the voltage profile, and as a solution indicates the power factor correction. The Hydro-Quebec system in Canada, the demand for small generators connection is increased [5].

Recently, study [6] shows that rural electrification can be supplied by small hydropower through induction generator and intelligent controllers in more economic schemes and cost-effective options. Studies in [7] compares the use of conventional synchronous machines together with the static frequency converter (SFC) in the Kadamparai plant with substitution by a variable speed induction generators to utilize the grid load variation effectively. The results show that the plant can be operated by variable speed machines.

The parallel operation voltage and frequency control was performed in [8], where induction generator can provide constant power and does not have excitation control. The synchronous generator has variable excitation in different load conditions. The results also show that changing the reactive load consumption can be supplied by the synchronous generator, keeping the voltage constant to 1 pu. The induction generator operates at full rating and does not respond does not respond to load change in the consumer.

In the interconnected electric power system *IEPS* there is presence of a large number of synchronous generating units of high power and non-linear loads. The application of rules aiming to limit the harmonic content of tensions on possible values of maintaining acceptable power quality is recommended [9]. In [10] is presented tests that induction generator does not introduce harmonics in power system. [11] shows the repowering system using the common bus two machines of the same power, a synchronous generator and an induction generator. The results show that the induction generator reduces harmonic content in the common bus.

In [13] proposed the development of a simulation model for repowering steam plant, providing dark areas of links aimed at accelerating the power system restoration process services.

Recently, [14] conduct a study to evaluate the economic and repowering prospects of a plant into disuse in the territory of Petralia Sottana (Sicily). The work shows that the refurbishment of the plant "Catarrate" contributes to the energy independence of the local community, with an estimated annual production of renewable energy of approximately 220 MWh and at the same time, the preservation of industrial heritage.

This paper aims to repowering the system. Furthermore, the objective is that the induction generator insertion in the common bus to a synchronous generator, can improve the sinusoidal profile of voltage and current. Thus, it is noted that the induction generator is still a preferential path for harmonic currents becoming protection synchronous generator, which is a more expensive and less robust machine that induction one.

II. Mathematical Modeling

A. Three-Phase Induction Generator under Non-Sinusoidal Steady State

Fig. 1 presents electrical circuit that models the induction machine in non-sinusoidal steady state, where X_E is stator leakage reactance and E_{ah} is the h order harmonic component of voltage, induced in Phase a machine stator, by the magnetic field produced by sinusoidal spatial distribution of rotating magneto-motive force of h order, fmm_{E0h} [12].

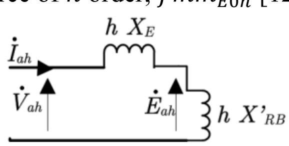


Fig. 1. Induction machine representative electrical circuit.

Considering odd values for h index, which are most likely harmonic components produced by non-linear loads, one can write:

$$\dot V_h = \dot Z_h \cdot \dot I_h \tag{1}$$

With such assumptions the equivalent circuit becomes purely inductive, and impedance $\dot Z_h$of the circuit is expressed by:

$$\dot Z_h = jh(X_E + k_R \cdot X'_{RB}) \tag{2}$$

As X'_{RB} has very similar value to X_E and $k_R$tends to one, can be a approach to accept $\dot Z_h$ to:

$$\dot Z_h \cong j2hX_E \tag{3}$$

Therefore, (1), (2) and (3), leads to:

$$\dot V_h \cong j2hX_E\dot I_h \tag{4}$$

B. Three-Phase Synchronous Generator under Non-Sinusoidal Steady State

For all phases of synchronous machine, and adopting usual nomenclature to represent harmonic reactance proposed in [12], we have (5) where r_E is per phase stator resistance, X_S is synchronous reactance at frequency ω and X_{af} is stator-rotor mutual reactance at frequency ω.

$$\dot V_h = [r_E + jhX_S] \cdot \dot I_h + j\frac{hX_{af}}{2} \cdot \dot I_{f(h)} \tag{5}$$

In practice $r_E \ll X_S$ and representing the last term by (6), leads to (7):

$$\dot E_h = j\frac{hX_{af}}{2} \cdot \dot I_{f_h} \tag{6}$$

$$\dot V_h \cong jhX_S\dot I_h + \dot E_h \tag{7}$$

Expression (7) suggests the circuit of Fig. 2.

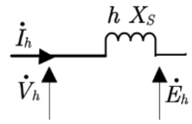


Fig. 2. Cylindrical rotor synchronous machine equivalent circuit.

From undertaken mathematical and physical analyzes, it is concluded that power flowing through terminals $\dot E_h$ is practically inductive reactive, therefore suggesting, there is only inductive impedance in circuit which relates $\dot V_h$ and $\dot I_h$, which may be represented by hX_S.

C. Association between Induction and Synchronous Generator

Assuming two machines, one synchronous and other an induction one, of same power, connected to same bus, Fig. 3, it is possible to make comparative analysis of harmonic current components in both.

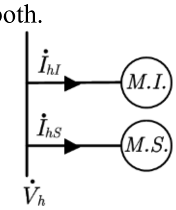


Fig. 3. Parallel machines.

Expressions (4), induction machine and (7), synchronous machine, can be rewritten as illustration of Fig. 3, and (8) and (9), respectively.

$$\dot V_h \cong j2hX_E\dot I_{hI} \tag{8}$$

$$\dot V_h \cong jh(X_S + X)\dot I_{hS} \tag{9}$$

Where X is equivalent reactance between terminals $\dot E_h$. Substituting (8) in (9) and through algebraic manipulation, it has:

$$\frac{\dot I_{hI}}{\dot I_{hS}} = \frac{X_S + X}{2 \cdot X_E} \tag{10}$$

Assuming threshold condition, where X is is negligible in comparison to X_S and $X_S = 10 \cdot X_E$, from (10) we have:

$$\frac{\dot I_{hI}}{\dot I_{hS}} = 5 \tag{11}$$

In expression (11) X_S represents phase leakage reactance of the synchronous machine, plus armature reaction, while X_E is stator leakage reactance of induction machine. By boundary condition, it is possible to ensure the inequality:

$$\dot I_{hI} > 5 \cdot \dot I_{hS} \tag{12}$$

In (12) it is conclude that in same bus, harmonic components of currents will flow with higher intensity to induction machine. This fact justifies the proposal of this work, of using induction machine as a means to absorb harmonic components of currents, attenuating its flow to synchronous machine. It follows that when the machine is seen only by the fundamental sinusoidal component, the power flowing in the rotor is almost exclusively active, while, when viewed for a single harmonic component, the power flowing in the rotor is almost entirely inductive reactive. It allows to assume the intensities as irrelevant, or even the direction of electromagnetic torque (motor or generator), to simulate the conditions of harmonic mitigation in synchronous machine.

III. METHODOLOGY

The methodology will be developed in following steps:

i. Modeling the illustrated electrical system in Fig. 4 with the characteristics Tab. I;
ii. Conducting testing connected to common bus nonlinear load N_L;
iii. Conducting testing connected to common bus nonlinear load N_L and synchronous generator S_G;
iv. Conducting testing connected to common bus nonlinear load N_L, synchronous generator S_G and an induction generator I_G.
v. Conducting testing connected to common bus nonlinear load N_L and an induction generator I_G.

The power values will be recorded in meter M_1 in order to prove the increase in power output. For more information on harmonics attenuation, the harmonic content will be recorded at the point of measurement M_1, M_2, M_3 and M_4 to have better understanding of harmonic flows in the system.

A. Connection Machine and Loads for Case Study 1

Laboratory tests will be carried out, for *IEPS* shown in Fig. 4, where M_1, M_2, M_3, M_4 and M_5 are points for quantities measurements.

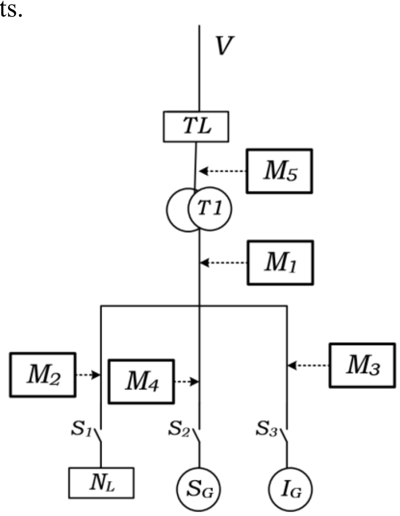


Fig. 4. Interconnected electrical power system - IEPS for Case Study 1.

Experimental tests of this work were performed in the laboratory with a system composed of two generating units, a synchronous and another induction. Both units are in parallel by feeding the first rectifier which constitute the nonlinear load. The N_L load is a resistive load of 500 watts, fed by a rectifier. To regulate properly the speed of generators, S_G and I_G, they used DC motors.

The Fig. 5 presents the equipment used in the laboratory.

Fig. 5. Equipments utilized in laboratory tests.

B. Connection Machine and Loads for Case Study 2

Laboratory tests will be carried out, for *IEPS* shown in Fig. 6, where M_1, M_2, M_3 and M_4 are points for quantities measurements.

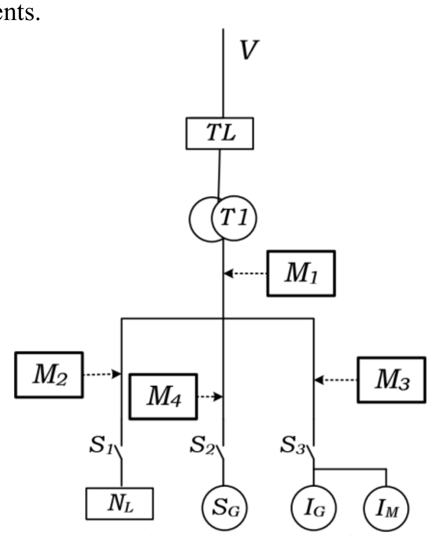
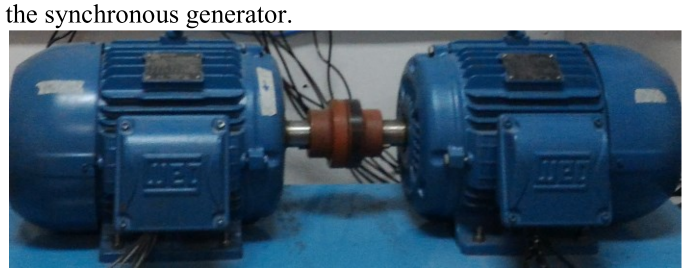


Fig. 6. Interconnected electrical power system - IEPS for Case Study 2.

Experimental tests of this work will be performed in the laboratory with system composed of two generating units, a synchronous and another induction. Both units will be in parallel by feeding nonlinear load N_L consisting of triac rectifier feeding sets of lamps. Two phases with total power of 5 kW and the third phase with 4kW. To regulate generators speed, S_G and I_G. were used diesel engine and induction motor with frequency inverter, respectively. Since the induction motor will be fed by the common bus, through S_3 key.

The Fig. 7 presents the equipment used in the laboratory, in which Fig. 7(a) the induction generator and Fig. 7(b) shows the synchronous generator.



(a) Induction Generator

(b) Synchronous Generator

Fig. 7. Equipments utilized in laboratory tests.

IV. Results

A. Case Study 1

1) Experimental Tests

Components and values of *IEPS* of Fig. 4 are reported in the Tab. I, along with their values.

Table I. Acronyms and Values of the Components from IEPS.

Variable	Components	Components Values of Used
S_G	Synchronous Generator (main generator)	2kVA, 230V, three-phase, salient, 4poles, 60Hz
I_G	Induction Generator	2kVA, 220V, three-phase, cage rotor, 4poles, 60Hz
N_L	Nonlinear Load	500W three-phase, 380V, 60 Hz
T_1	Transformador	5kW, 380/220 V, Δ/Y aterrado
S_1, S_2, S_3	Interrupter	

The main objective of *IEPS* experimental testes is to obtain the increment of power generated plant at the measurement point M_1 and results of total harmonic distortion of current THD_i, measured in points M_1, M_2, M_3 and M_4, maintaining total harmonic distortion of voltage THD_v within standard limits.

The limit established by standard and presented in *IEEE-Std-519-1992*, [9], for voltage harmonic distortions, varies according to the voltage class in the measured point. In this case, as the measurement points has a 380 V voltage level, the limit of total harmonic distortion of voltage THD_v should be 5.0% and the limit of the individual distortion should be 3.0%.

2) Repowering

The Tab. II shows the operating conditions of the synchronous generator S_G and the induction generator I_G for experimental testing. The values of active, reactive and total power and power factor of the S_G and I_G were obtained in the measurement points and M_4 and M_3, respectively for loads N_L. The Tab. III present data of active, reactive and total power and power factor to the measuring point M_1 for the various configurations proposed to loads N_L.

Table II. Active, Reactive and Total Power and Power Factor in S_G e I_G for N_L.

Operation	P(W)	Q(VAr)	S(VA)	fp
S_G	-1085	-3595 I	3767	0.291
I_G	-1007	3783 C	3767	0.256

Table III. Active, Reactive and Total Power and Power Factor in $M_1\ for\ N_L$.

Configuration	P(W)	Q(VAr)	S(VA)	fp
N_L	500	174.9 I	531.3	0.943
$S_G + N_L$	-681	-3379 I	3454	0.2
$S_G + I_G + N_L$	-1644	818 C	1865	0.92
$I_G + N_L$	-514	3949 C	3995	0.133

The Tab. III present the data powers in secondary side of the transformer for various configurations with two types of nonlinear load connected to the system. In the configuration where only N_L is connected, the network is providing active power of 500W. With the synchronous generator connection, configuration $S_G + N_L$, the network is providing active power of 681 W. Connecting the induction generator, setting $S_G + I_G + N_L$, the network is receiving active power of 1644 W. Note that with the inclusion of the induction generator is repowering of the system. Note also that the power factor in M_1 the configuration $S_G + I_G + N_L$ is 0.92.

3) Harmonics

The values shown in Tab. IV and Tab. V illustrate for a total harmonic distortion of voltage and for a total harmonic distortion of current to the measuring points M_1, M_2, M_3 , M_4 and M_5 , respectively.

By measuring M_1, presented in Tab. IV and Tab. V is observed that the value total harmonic distortion of voltage increases of 1.9% for 2.1% in the configuration $S_G + N_L$, and mitigates to 1.7% in $I_G + N_L$. In the setting $S_G + I_G + N_L$, mitigates the amount to 1.5%. The total harmonic distortion of current generated for the setting N_L in M_1 is 23.1%. In setting $S_G + N_L$ mitigates the value to 4.6% and setting $I_G + N_L$ mitigates the value to 5.6%. In the setting $S_G + I_G + N_L$ mitigates the amount to 12.1%. This proves that both the synchronous generator as induction generator mitigates the harmonic distortion in IEPS. In setting $S_G + I_G + N_L$ the value of THD_i is 2.8% in M_3 and 1.5% in M_4 and the value of THD_v is 1.5% in M_3 and 1.4% in M_4, showing that the induction generator behaves as a preferential path for harmonic.

Table IV. Values of *THDv* (%) in $M_1, M_2, M_3\ e\ M_4$ with N_L.

	TDHv			
Configuração	M_5	M_1	M_3	M_4
CNL	1.7	1.9	-	-
SG+CNL	1.7	2.1	-	2.0
SG+IG+CNL	1.6	1.5	1.5	1.4
IG+CNL	1.7	1.7	1.7	-

Table V. Values of *THDi* (%) in $M_1, M_2, M_3\ e\ M_4$ with N_L.

	TDHi			
Configuração	M_5	M_1	M_3	M_4
CNL	17.8	23.1	-	-
SG+CNL	4.3	4.6	-	1.8
SG+IG+CNL	17.9	15.4	2.8	1.5
IG+CNL	5.5	5.6	3.3	-

These results reaffirm the proposed use of induction generators to mitigate the harmonics in the main generators of power plants.

B. Case Study 2

1) Experimental Tests

Components and values of *IEPS* of Fig. 6 are reported in the

Tab. VI, along with their values.

Table VI. Acronyms and Values of the Components from IEPS.

Variable	Components	Components Values of Used
S_G	Synchronous Generator (main generator)	37kVA, 380V, three-phase, salient, 4poles, 60Hz
I_G	Induction Generator	7.5kVA, 380V, three-phase, cage rotor, 4poles, 60Hz
N_L	Nonlinear Load	14kW three-phase, 380V, 60 Hz
S_1, S_2, S_3	Interrupter	

2) Repowering

The operating conditions of synchronous generator S_G and induction generator I_G for experimental testing are presented in Tab. VII. The values of active, reactive and total power and power factor were obtained in measurement points M_4 and M_3, for loads N_L. The Tab. VIII present data of active, reactive and total power and power factor to measuring point M_1 for various configurations proposed to loads N_L. The excitement of synchronous generator was tuned to get the best power factor N_L on $S_G + I_G + N_L$ configuration.

Table VII. Active, Reactive and Total Power and Power Factor in S_G e I_G for N_L.

Operation	P(W)	Q(VAr)	S(VA)	fp
S_G	-23003	-7912	24343	0.945
I_G	-4011	4737	6214	0.645

Table VIII. Active, Reactive and Total Power and Power Factor in M_1 for N_L.

Configuration	P(W)	Q(VAr)	S(VA)	fp
N_L	1452	2996	5713	0.254
$S_G + N_L$	-21682	-4751	22699	0.955
$S_G + I_G + N_L$	-19847	-553	22011	0.895
$I_G + N_L$	2830	8985	13332	0.334

The Tab. VIII presents the data powers in secondary side of the transformer for various configurations with types of nonlinear load connected to system. In the configuration where only N_L is connected, the network is providing active power of 1452 W. In $S_G + N_L$ configuration, with synchronous generator connection, that provides active power of 23003 W, as Tab. VII. Network starts to receive active power of 21682 W in the case.

Connecting induction generator, setting $S_G + I_G + N_L$, the network is receiving active power of 19847 W. In this case, has a load receiving 452 W, synchronous generator providing 23003 W, induction generator providing 4011 W, as Tab. VII. The primary machine of induction generator, connected to S_3 key receive 5368 W. Note that with induction generator inclusion, the system is repowering. Note also that the power factor in M_1 the configuration $S_G + I_G + N_L$ is 0.895, this is due to the power factor of synchronous generator manufacturer that is 0.8.

3) Harmonics

The values shown in Tab. IX and Tab. X illustrate for a total harmonic distortion of voltage and for a total harmonic distortion of current to measuring points M_1, M_2, M_3 and M_4.

Table IX. Values of *THDv* (%) in M_1, M_2, M_3 e M_4 with N_L.

	TDHv			
Configuration	M_1	M_2	M_3	M_4
CNL	1.6	1.6	-	-
SG+CNL	1.5	1.5	-	-
SG+IG+CNL	1.5	1.5	1.5	1.4
IG+CNL	1.5	1.5	1.5	-

Table X. Values of *THDi* (%) in M_1, M_2, M_3 e M_4 with N_L.

	TDHi			
Configuration	M_1	M_2	M_3	M_4
CNL	137.9	137.9	-	-
SG+CNL	21.9	-	-	3.4
SG+IG+CNL	41.9	137	3.7	3.4
IG+CNL	81.2	137.1	3.5	-

By measuring M_1, presented in Tab. IX and Tab. X is observed that the value total harmonic distortion of voltage is 1.6% in N_L configuration and mitigates to 1.5% in configurations $S_G + N_L$, $I_G + N_L$, and $S_G + I_G + N_L$. The total harmonic distortion of current generated for the N_L setting in M_1 is 137.9%. In setting $S_G + N_L$ mitigates the value to 21.9% and setting $I_G + N_L$ mitigates the value to 41.9%. In the setting $S_G + I_G + N_L$ mitigates to 81.2%. This proves that both synchronous and induction generator decrease the harmonic distortion in *IEPS*. In setting $S_G + I_G + N_L$ the value of THD_i is 3.7% in M_3 and 3.4% in M_4 and the value of THD_v is 1.5% in M_3 and 1.4% in M_4, showing that the induction generator behaves as a preferential path for harmonic.

These results reaffirm the proposed use of induction generators to repowering and attenuation the harmonics in the main generators of power plants.

The Fig. 8 shows the current waveform with non-linear load connected in system. The total harmonic distortion of voltage THD_v and current THD_i with nonlinear load connected to system was 1.6% and 137.9%, respectively. All individual harmonics were significant with values above 18.1%, individual harmonic values are shown in Tab. XI.

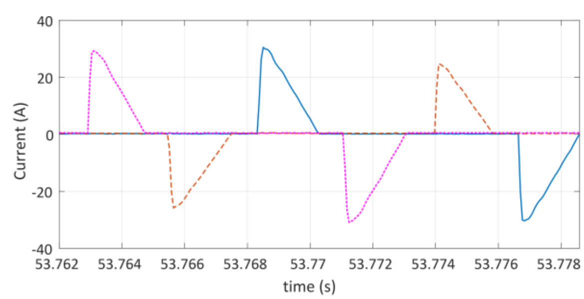


Fig. 8. Waveform in M_1 with THD_i- N_L connected.

Table XI. Values in M_1 with THD_i- N_L connected.

THD_v	1.6%		
THD_i	137.9%		
Harmonic	AB	BC	CA
60 Hz (Fnd))	100%	100%	100%
180 Hz (h^3)	89.2%	89.5%	89.4%
300 Hz (h^5)	70.0%	70.2%	70.8%
420 Hz (h^7)	48.1%	48.3%	49.3%
540 Hz (h^9)	29.9%	30.2%	30.6%
660 Hz (h^{11})	21.4%	21.1%	20.7%
780 Hz (h^{13})	20.7%	19.9%	19.1%
900 Hz (h^{15})	19.5%	18.8%	18.1%

The Fig. 9 shows the current waveform, after entry of synchronous generator with non-linear load connected to system. The total harmonic distortion of voltage THD_v and current THD_i after synchronous generator switching with a nonlinear load connected was 1.5% and 21.9%, respectively.

The total harmonic distortion of current THD_i attenuated from 137.9% to 21.9% and the most significant individual harmonic orders were the third order h_3 an attenuation from 89.5% to 14.1% and fifth order h_5 with an attenuation from 70.8% to 13.4%, the values of the other harmonics are listed in Tab. XII. The reduction is due to the fact that the synchronous generator is overexcited in order to supply reactive induction generator, while maintaining the power factor as close to 0.92 in M_1, when the configuration $S_G + I_G + N_L$.

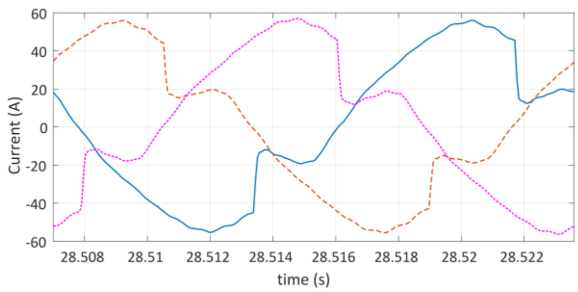


Fig. 9. Waveform in M_1 with THD_i- $S_G + N_L$ connected.

Table XII. Values in M_1 with THD_i- $S_G + N_L$ connected.

THD_v	1.5%		
THD_i	21.9%		
Harmonic	AB	BC	CA
60 Hz (Fnd))	100%	100%	100%
180 Hz (h^3)	13.7%	13.0%	14.1%
300 Hz (h^5)	13.4%	11.4%	13.0%
420 Hz (h^7)	8.3%	6.5%	8.3%
540 Hz (h^9)	5.0%	3.9%	4.7%
660 Hz (h^{11})	3.6%	2.7%	3.4%
780 Hz (h^{13})	3.0%	2.1%	2.7%
900 Hz (h^{15})	3.2%	2.3%	2.9%

The Fig. 10 shows the current waveform, after induction generator input with synchronous generator and non-linear load connected to system. The total harmonic distortion of voltage THD_v and current THD_i after induction generator switching with a synchronous generator and a nonlinear load connected was 1.5% and 41.9%, respectively. The total harmonic distortion of current THD_i increased from 21.9% to 41.9% and the most significant individual harmonic orders were the third order h_3 an increment from 14.1% to 45.6% and fifth order h_5 with an increment from 13.4% to 38.3%. The values of the other harmonics are listed in Tab. XIII. The purpose of this configuration is to keep the power factor as close to 0.92 in M_1, which means that there is reduction of harmonics in relation to the configuration N_L, but increase over the $S_G + N_L$.

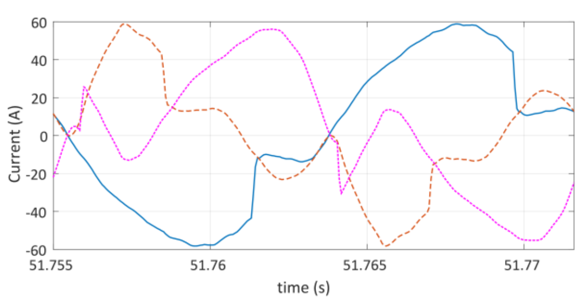


Fig. 10. Waveform in M_1 with THD_i- $S_G + I_G + N_L$ connected.

Table XIII. Values in M_1 with THD_i- $S_G + I_G + N_L$ connected.

THD_v	1.5%		
THD_i	41.9%		
Harmonic	AB	BC	CA
60 Hz (Fnd))	100%	100%	100%
180 Hz (h^3)	12.2%	35.3%	45.6%
300 Hz (h^5)	12.1%	38.3%	27.5%
420 Hz (h^7)	7.4%	0.6%	9.3%
540 Hz (h^9)	4.3%	8.3%	4.1%
660 Hz (h^{11})	3.1%	3.5%	1.4%
780 Hz (h^{13})	2.7%	2.2%	1.0%
900 Hz (h^{15})	2.8%	5.3%	1.6%

The Fig. 11 shows the current waveform, after entry of induction generator with non-linear load connected to system. The total harmonic distortion of voltage THD_v and current THD_i after synchonous generator swiching off, with the induction generator and a nonlinear load connected to system was 1.5% and 81.2%, respectively. The total harmonic distortion of current THD_i attenuated from 137.9% to 81.2% and the most significant individual harmonic orders were the third order h_3 an attenuation from 89.5% to 83.0% and fifth order h_5 with an increment from 70.8% to 76.6%, the values of the other harmonics are listed in Tab. XIV. It shows a decrease with respect to N_L configuration, but it is important to note that with induction generator connection there feeding of primary machine that increases distortion at M_3 measuring point. Furthermore, the induction generator is a smaller machine than the synchronous one.

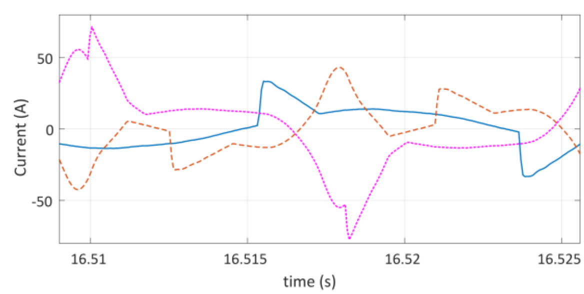


Fig. 11. Waveform in M_1 with THD_i- $I_G + N_L$ connected.

Table XIV. Values in M_1 with THD_i- $I_G + N_L$ connected.

THD_v	1.5%		
THD_i	81.2%		
Harmonic	AB	BC	CA
60 Hz (Fnd))	100%	100%	100%
180 Hz (h^3)	37.6%	83.0%	61.1%
300 Hz (h^5)	29.4%	76.6%	30.5%
420 Hz (h^7)	20.7%	5.8%	10.1%
540 Hz (h^9)	12.6%	20.6%	3.5%
660 Hz (h^{11})	9.1%	9.1%	1.0%
780 Hz (h^{13})	8.8%	6.8%	1.2%
900 Hz (h^{15})	8.3%	11.8%	2.1%

The individual harmonic distortion of current generated at M_1 is higher than N_L configuration. Both for $S_G + N_L$ setting as for $S_G + N_L$ there is an attenuation in individual distortions, to be more significant in configuration $S_G + N_L$.

It is necessary to conduct a detailed analysis $S_G + N_L$ and $I_G + N_L$ configurations, where it is important to consider that: i) the synchronous generator is configured to supply the reactive induction generator keeping the power factor as 0.92 in M_1, which makes work in the region where shows attenuation characteristic of harmonics; ii) at M_3 measuring point is included the induction generator and the primary machine, increasing total harmonic distortion of this configuration, since the primary machine still has power biphasic and iii) the induction generator is active power machine approximately five times smaller than synchronous one.

V. Conclusions

This work confirmed through the results that induction generator in connection with a synchronous generator and a nonlinear load has the ability, to increase the power generated, available for the electrical system, besides increasing the power generation available for the electrical system, attenuating harmonic distortion current and voltage in commom bus. The induction machine besides showing low cost, robustness, simple construction, lower cost and less maintenance compared with synchronous machine, repowering the system. The results showed that harmonic distortion bus suffers reductions for synchronous generator connection as for induction generator connection. It is noted in results that induction generator provided a preferred path for current harmonic order, even when two machines produce or consume equivalent and proportional reactive power.

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