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A DISTRIBUTION SYSTEM FED BY MULTI PHASE CONVERTER UNDER FLC

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Abstract— *This paper presents the operation of a distributed generation (DG) system driven by a dc-dc increase convertor and a dc-ac voltage supply electrical converter (VSI) interfaced with the facility grid underneath the FUZZY logic management strategy. to make a stable mode once totally different types of masses area unit connected domestically or once operating underneath contingency, the increase convertor should regulate the dc link voltage, permitting the VSI to stabilize its terminal voltage. the facility flow between the grid and also the metric weight unit is controlled by applying a power/voltage methodology that regulates the amplitude and also the displacement of the grid voltage synthesized by the metric weight unit, whereas a phase-locked loop algorithmic program is employed to synchronize the grid and metric weight unit. to boot, a collection of simulations area unit performed freelance of the load sort or its work regime (whether it's connected to the grid).*

I. INTRODUCTION

The use of distributed generation (DG) sources is presently being thought of as an answer to the growing issues of energy demand [1]. excluding the ensuing reduction within the size of the generating plants and therefore the chance of standard implementation, decigram systems supported renewable energy sources [2] (photovoltaic, fuel cells, and storage systems like immoderate capacitors and batteries [1]) square measure of nice interest thanks to their low environmental impact [3] and technical benefits like enhancements in voltage levels and reduced power losses once a decigram system is put in in radial lines [4]. decigram systems conjointly promote cogeneration [5] and improve overall system potency [6]. A decigram system operational at high performance needs an in depth analysis of the feeder wherever the decigram are put in [7], and AN assessment of the load sort the decigram should offer domestically and its operating regime. while not these needs, the consequences of decigram is also additional harmful than beneficial: the insertion of recent generation sources within the distribution system might cause transient effects thanks to shift operations, dynamical short-circuit levels, lower margin of stability, and inversion of the facility flow through the distribution system, inflicting incorrect operations of the protection devices and islanding partially of the system [8]. additionally, the decigram operation shouldn't exceed the boundaries established by international standards for the subsequent parameters: harmonic distortion [9], voltage imbalance, voltage fluctuations, and quick transients, whether or not the native load is unbalanced, nonlinear, or a dynamic load, like a motor [10].

Recently, the utilization of power or current within the d-q synchronous organisation [11]–[14] as management variables to command the voltage supply electrical converter (VSI) connected to the grid has generated hefty interest from the scientific community. With either methodology, before or when the contingency takes place, the management variable remains an equivalent, creating the decigram operate with restricted capability to provide the load.

On the opposite hand, 2 management algorithms were planned to boost the grid-connected and intentional-islanding operations ways in [15], within which the decigram system should sight things and switch from power or current to voltage as a sway variable to supply constant rms voltage to the native hundreds.

In [16] and [17], the facility flow is set by dominant the amplitude and angle of displacement between the voltage made by the decigram and therefore the grid voltage [18], i.e., the management variable is that the same before and when the islanding mode happens.

The voltage management provides the aptitude to provide totally different types of hundreds to the decigram system, like linear, nonlinear, and motor, balanced, or unbalanced [19], albeit the decigram operates within the islanding mode. These types of controls square measure appropriate for DGs operational in parallel as every of the DGs square measure connected to the grid through a distribution electrical device (DT) [20]. Conversely, the opposite approaches introduced in [21], [22] square measure more practical. This paper analyzes the consequences caused by fifty to 5000-kVA decigram sources inserted into the distribution system, whether or not the native load is linear or nonlinear, or if the grid is working below abnormal conditions. Section II details the strategy wont to drive

, changing short-circuit levels, lower margin of stability, and inversion of the power flow through the distribution system, causing erroneous operations of the protection devices and islanding in part of the system [8]. In addition, the DG operation should not exceed the limits established by international standards for the following parameters: harmonic distortion [9], voltage imbalance, voltage fluctuations, and fast transients, whether the local load is unbalanced, nonlinear, or a dynamic load, such as a motor [10].

Recently, the use of power or current in the d-q synchronous reference frame [11]–[14] as control variables to command the voltage source inverter (VSI) connected to the grid has generated considerable interest from the scientific community. With either method, before or after the contingency takes place, the control variable remains the same, making the DG operate with limited capability to supply the load.

On the other hand, two control algorithms were proposed to improve the grid-connected and intentional-islanding operations methods in [15], in which the DG system must detect the situation and switch from power or current to voltage as a control variable to provide constant rms voltage to the local loads.

In [16] and [17], the power flow is determined by controlling the amplitude and angle of displacement between the voltage produced by the DG and the grid voltage [18], i.e., the control variable is the same before and after the islanding mode occurs.

The voltage control provides the capability to supply different kinds of loads to the DG system, such as linear, nonlinear, and motor, balanced, or unbalanced [19], even if the DG operates in the islanding mode. These kinds of controls are suitable for DGs operating in parallel as each of the DGs are connected to the grid through a distribution transformer (DT) [20]. Conversely, the other approaches introduced in [21], [22] are more effective. This paper analyzes the effects caused by 50 to 5000-kVA DG sources inserted into the distribution system, whether the local load is linear or nonlinear, or if the grid is operating under abnormal conditions. Section II details the method used to drive

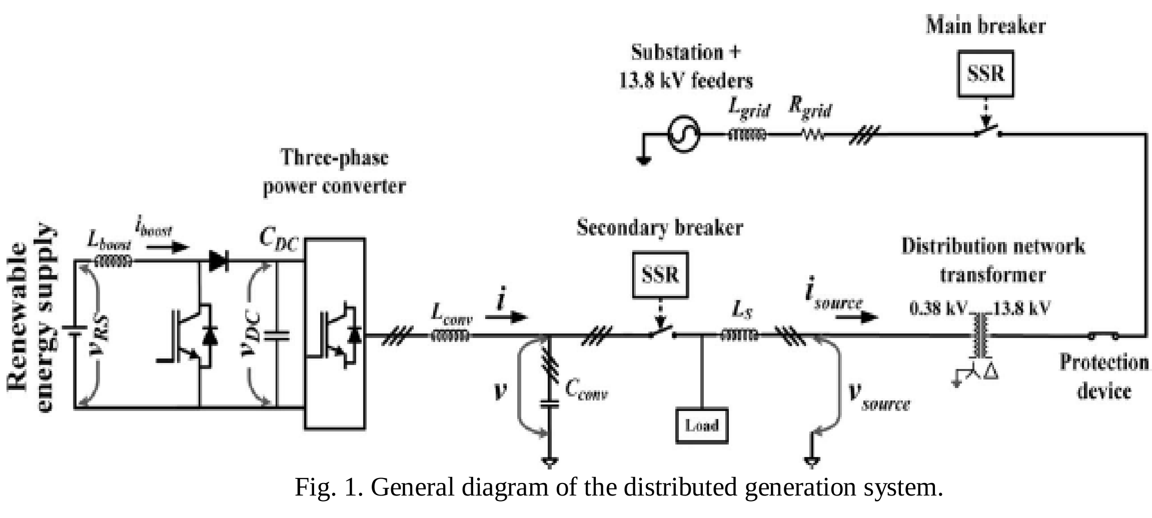

Fig. 1. General diagram of the distributed generation system.

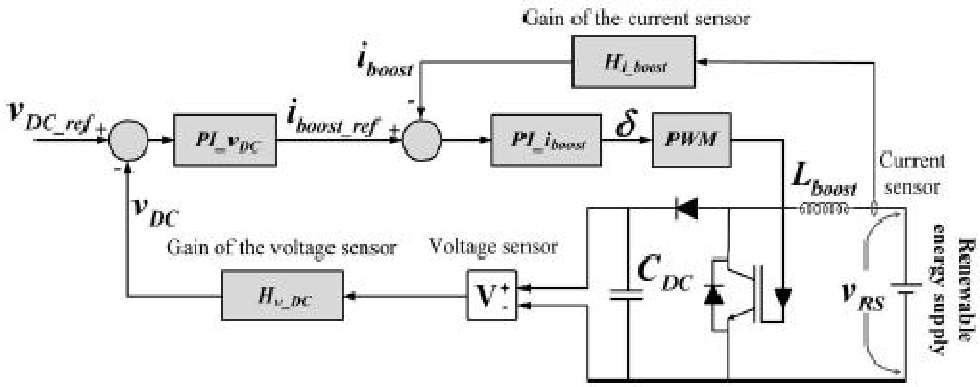

Fig. 2. Block diagram of the dc voltage/current control.

both converters. Section III discusses the technique to control the power flow through the grid. Sections IV and V show the simulation setup to confirm the previous analysis, while the main points presented in this paper appear in the conclusion.

II. CHARACTERISTICS OF THE DG SYSTEM

Fig. 1 shows a diagram of the system used to analyze a typical connection of a DG system to a specific feeder, although studies to determine the best site for DG insertion should be performed before the operation analysis [7]. A power plant represents a secondary source (DG systems), while in this study the standard grid is a basic configuration system found in 1547 standard (simulated system) [23]. Furthermore, the primary energy used in the proposed DG system is the same as the previously mentioned renewable energy sources.

A dc-dc converter is employed to equalize the dc link voltage and deliver energy for fast transients when required by the local load, while a dc-ac converter is used to guarantee the power quality delivered to customers (local load) and the specific feeder. To avoid disturbances between the dc-ac converter and the feeder, a phase-locked loop (PLL) algorithm [11] associated with the zero voltage crossing detectors was used [24], [25]. Appendix I shows the design procedure for key passive components.

A. DC-DC Converter

A dc-dc step-up converter was used as an interface between the dc source and dc link of the three-phase dc-ac converter, as shown in Fig. 2. The step-up converter boosts the dc voltage and supplies the fast transients of energy required for the local load, thereby minimizing disturbances in the feeder current. The behavior of the step-up converter is similar to a voltage source, and the power it delivers to the grid depends on the point of maximum power (PMP) defined by the dc source [1]. The PMP is obtained using a tracking algorithm [26], based on the primary energy source. To keep the converters operating in a stable mode, proportional-integral (PI) controllers were used as a control technique to stabilize the L_{boost} current and dc voltage (v_{DC}).

A method based on phase-margin (m_f) and cutoff frequency (FCL) was used to obtain the PIs constants (1) and (2) [2], [16], where the open loop

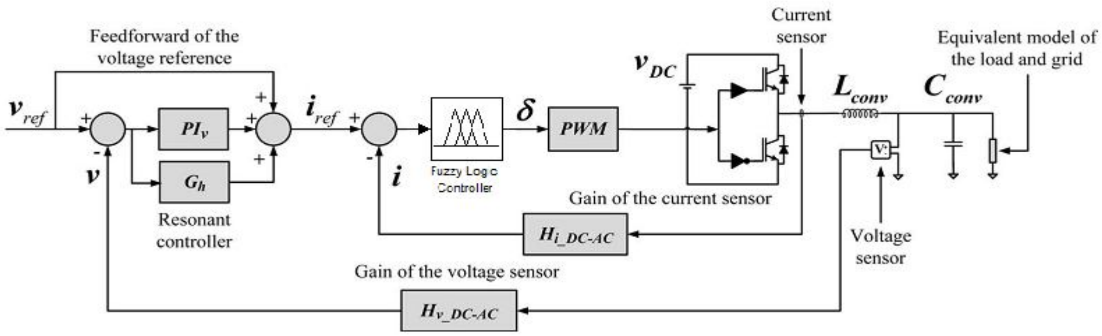

Fig. 3. Block diagram of the ac voltage/current control.

gain (*GOL*), angular frequency (ω_{FCL}), and *mf* define the PIs constants (k_{prop} and k_{int}) [16].

$$k_{prop}\frac{G_{OL}}{\omega F_{cL}} = 1 \quad (1)$$

$$k_{int} = k_{prop}\frac{\omega F_{cL}}{\tan(mf)} \quad (2)$$

THE FUZZY LOGIC CONTROLLER

Fuzzy logic control is a non-mathematical decision algorithm that is based on an operator's experience. The fuzzy logic controller can easily be programmed to handle this region.

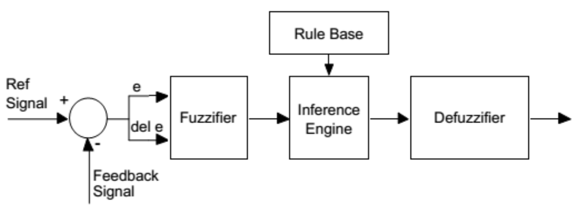

FIG 4 Structure of Fuzzy Logic Controller

FUZZIFIER

Fuzzy logic uses linguistic variables instead of numerical variables. In a closed loop control system, the error (e) between the reference voltage and the output voltage and the rate of change of error (del e) can be labeled as zero (ZE), positive small (PS), negative small (NS), etc. Inthe real world, measured quantities are real numbers (crisp). The process of converting a numerical variable (real number) into a linguistic label (fuzzy number) is called fuzzification. Figure shows the membership functions that are used to fuzzify the inputs.

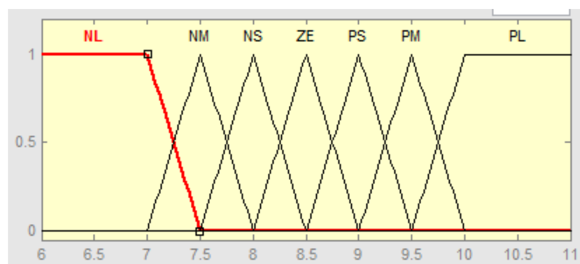

Fig 5 Input1 membership functions

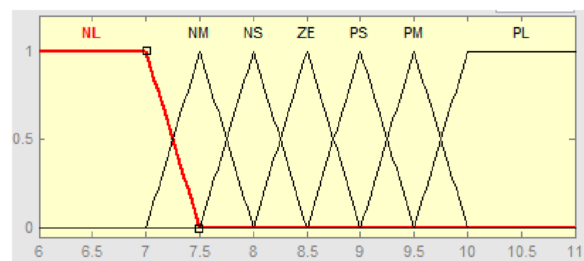

Fig 6 Input2 membership functions

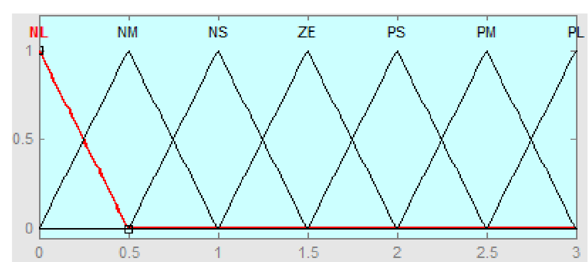

Fig 7 output1 membership functions

The inputs are mapped into these membership functions and a degree of membership is found for how much the input belongs to that particular linguistic label. The membership can take on a value from zero to unity for each of the linguistic labels. The waveforms are evenly distributed about the range of operation of the variables. For each of the input

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and output variables, the following seven linguistic labels are assigned to the membership functions:

NL = Negative Large
NM = Negative Medium
NS = Negative Small
ZE = Zero
PS = Positive Small
PM = Positive Medium
PL = Positive Large

Once the membership is found for each of the linguistic labels, an intelligent decision can be made unto what the output should be. This decision process is called inference.

TABLE I
Fuzzy Logic Rule Table

e\de	**NL**	**NM**	**NS**	**ZE**	**PS**	**PM**	**PB**
NL	PL	PL	PL	PL	PM	PS	ZE
NM	PL	PL	PM	PM	PS	ZE	NS
NS	PL	PM	PS	PS	NS	NM	NL
ZE	PL	PM	PS	ZE	NS	NM	NL
PS	PL	PM	PS	NS	NS	NM	NL
PM	PM	ZE	NS	NM	NM	NL	NL
PL	ZE	NS	NM	NL	NL	NL	NL

INFERENCE

In conventional controllers, there are control laws, which are combinations of numerical values that govern the reaction of the controller. In fuzzy logic control, the equivalent term is rules. Rules are linguistic in nature and allow the operator to develop a control decision in a more familiar human environment [4]. A typical rule can be written as follows: If the “voltage” is negative large (NL), AND the “rate of change of voltage error” is negative large (NL), then the “field current” is positive large (PL). In this design, a minimum correlation inference technique was used. This means that the logic

membership that was equal to the minimum of the two inputs, voltage – NL and rate of change of voltage – NL. For example

Membership (V – NL) = .8 Membership (del V – NL) = .2

(.8) AND (.2) = .2

operation of AND will return the minimum of all inputs. For the linguistic rule stated earlier, the output, field current - PL, would receive a The rules of a fuzzy logic controller give the controller its intelligence, assuming the rules are developed by a person who has a experience with the system to be controlled.

A programmer with more experience with the system will create a better controller. In the case of the fuzzy logic synchronous generator controller, the desired effect is to keep the output voltage of the generator at its rated voltage under varying loads. From this desired goal, rules are made for every combination of voltage and rate of change of voltage on what the field currentshould be in order to stabilize the generator. It is convenient when dealing with a large number of combinations of inputs, to put the rules in the form of a rule table. Figure 6 shows the rule table for controlling the synchronous generator output voltage where Del Voltrefers to the rate of change of output voltage. After the rules are evaluated, each output membership function will contain a corresponding membership. From these memberships, a numerical (crisp) value must be produced. This process is called defuzzification.

DEFUZZIFICATION

Defuzzification plays a great role in a fuzzy logic based control system. It is the process in which the fuzzy quantities defined over the output membership functions are mapped into a non-fuzzy (crisp) number. It is impossible to convert a fuzzy set into a numeric value without loosing some information. Many different methods exist to accomplish defuzzification. Naturally there are trade-offs to each method.

TABLE II
MODIFIED PARAMETERS OF THE CONVERTERS

V_{DC}(v)	$C_{DC}(\mu F)$	$H_{i\ boost}$	$H_{v\ DC}$	$H_{i_{DC}\ AC}$
330	2800	1/12	1/360	1/12

The line model employed in the simulations took into account the Bergeron’s traveling wave method used by the Electromagnetic Transients Program, which utilized wave propagation phenomena and line end reflections. Additionally, a set of switches was inserted between the DGs and distribution system, isolating them from each other to avoid the DG system supplies loads (loads placed in neighboring feeders where the DG was installed) connected to the high voltage side of the distribution transform. Due to the high level of power and voltage, 12 kHz was used as the PWM switching frequency for both converters.

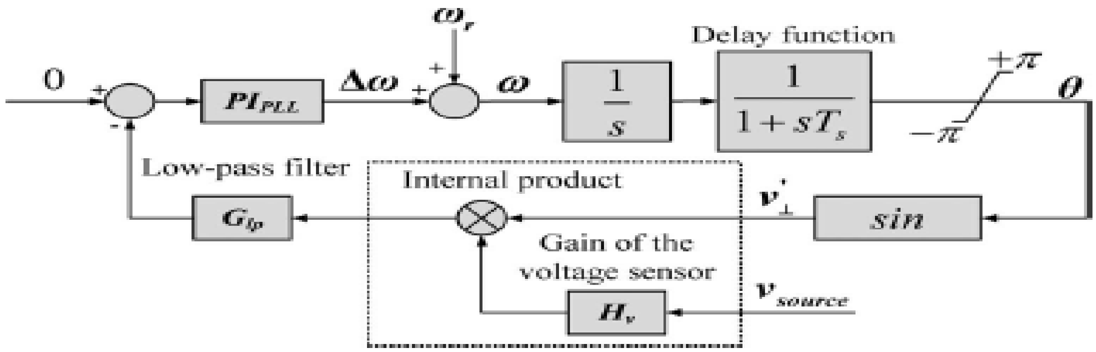


Fig. 8. PLL algorithm.

II. POWER CONTROL THROUGH THE FEEDER
Energy produced by the renewable energy sources can be transferred to the grid by controlling the amplitude of the voltage produced by the DG, and the angle between the grid voltage and the DG voltage (β angle) through a coupling inductor (LS) [16], [18]. This serves as an additional inductance placed to connect the DG to the grid, or the leakage inductance of the DT. If LS is a DT parameter, *vsource* must be measured on the high voltage side of the distribution network transformer.

To achieve a controlled power flow from the DG to the grid, the DG voltage angle ($\boldsymbol{V}_A$) must be ahead of the grid voltage angle ($\boldsymbol{V}_{Asource}$). When this occurs, the DG delivers active power to the grid, as shown in Fig. 5 [28]. The same analysis can be applied to the ac voltage amplitude produced by the DG: if the amplitude of $\boldsymbol{V}_A$ is greater than $\boldsymbol{V}_{Asource}$ the DG delivers reactive power to the grid; however, if the amplitude of $\boldsymbol{V}_A$ is less than $\boldsymbol{V}_{Asource}$ the DG absorbs reactive power from the grid.

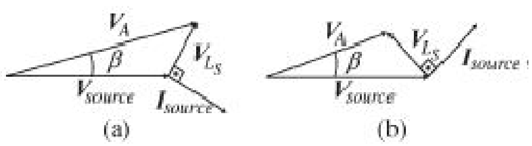


Fig.9. Phasor diagrams. (a) Delivering active and reactive power. (b) Delivering active and absorbing reactive power.

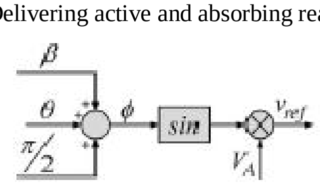


Fig. 10. Determination of the voltage reference.

The β angle is determined by the average power flowing to the grid (P_{source}), the connection reactance (X_{LS}), the rms phase voltage ($V_{Asource}$) synthesized by the grid, and the rms voltage produced (V_A) by the DG according to (10). After defining the β angle, the DG voltage amplitude of $\boldsymbol{V}_A$ must be adjusted according to (11), where $V_{Asource}$ and X_{LS} are the same parameters described in (10). If Q_{source} = 0 the unity power factor (PF) to the feeder is obtained [34]. Additionally, L_S is designed for a small voltage variation on the ac local voltage produced by the dc-ac inverter [16].

In Fig. 10, the voltage reference (v_{ref}) of the dc-ac power converter is determined by displacing θ by $\pi/2$ and adding the β angle to the result. The φ angle is then used as the argument of a sinusoidal function and multiplied by VA to obtain the voltage reference that must be synthesized at the VSI terminals

$$\beta = sin^{-1}\left(\frac{P_{source}|X_{LS}|}{V_{Asource}V_A}\right) \quad (9)$$

$$V_A = \sqrt{2}\left(\frac{V_{Asource}^2 - Q_{source}|X_{LS}|}{V_{Asource}\cos\beta}\right) \quad (10)$$

IV. SIMULATION ANALYSIS
Simulations were performed using MatLab/Simulink software, as shown in Fig. 1.

A. Connection and Power Transfer
Two procedures are required to connect the DG system to the feeder. First, an algorithm must be used to synchronize v_{source} with the voltage produced by the converter v. After synchronization, the algorithm to detect zero crossing of v_{source} must be initiated. When this is done, the switch connecting both systems is closed, minimizing the transient effects to the feeder (which occur up to 0.2 s).

Subsequently, a soft transfer (40kVA/s) of power starts at 0.25 s of the simulation range, followed by a base load operation. Due to the method used synchronization and soft transfer of power minimal disturbances are observed in the grid, as shown in Figs. 7 and 8. However, when the soft transfer of power is completed, two groups of resistive loads are connected within a short time interval (one, demanding 70 kW, is inserted at 0.8 s; the other, demanding 60 kW, is connected at 1.3 s).

Due to load capability, the current flowing through the grid inverts its direction, making additional power come from the grid. At the moment of the load connection, most of the electric variables are submitted to fast transients. However, this is not observed in the grid voltages because the short-circuit power of the grid is higher than the short-circuit power of the DG. To verify the power quality delivered to customers, total harmonic distortion (THD) of the DG voltage is well below 5%, whereas the PF is close to unity.

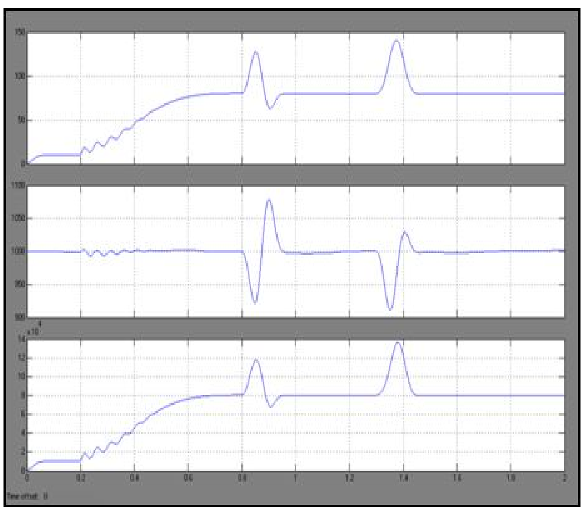


Fig.11. Operation of the boost converter.

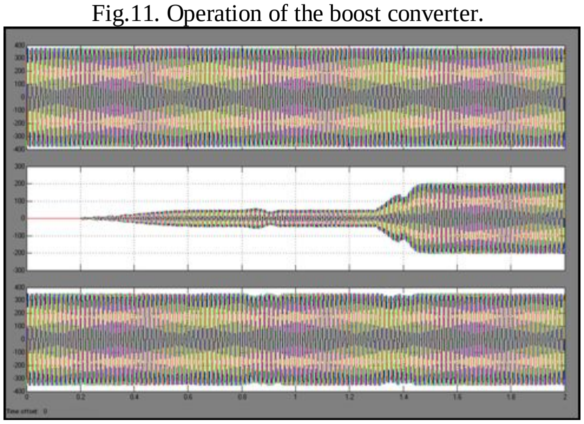


Fig.12. DG absorbing active power from the grid.

B. Nonlinear Load

Another issue to be analyzed is the influence of a nonlinear load connected to the DG terminals. In this case, the control technique used to synthesize the ac voltage by the inverter plays an important role. In fact, it reduces the impedance of the inverter, making the DG system compensate the local load harmonics. In this test, the load is inserted at 0.4 s and the DG is connected to the grid at 2 s, remaining so for 6 s. To observe the system's capability, the minimal value of active and reactive power flows through the grid, with the nonlinear load represented by a non controlled three-phase power rectifier plus *RC* load that demands around 50 kVA from the DG. In this operation mode, the THD of the voltage imposed by the VSI rises to 3%, even with the resonant controller compensating the 1st, 3rd, and 5th to 15th harmonics, however, the THD of the load current achieves more than 115%. To observe what happens with the DG system, a short time interval (1.96 to 2.04 s) before and after the connection with the grid is presented in Fig.13, which demonstrates the DG capability to supply nonlinear loads in the connected or isolated modes.

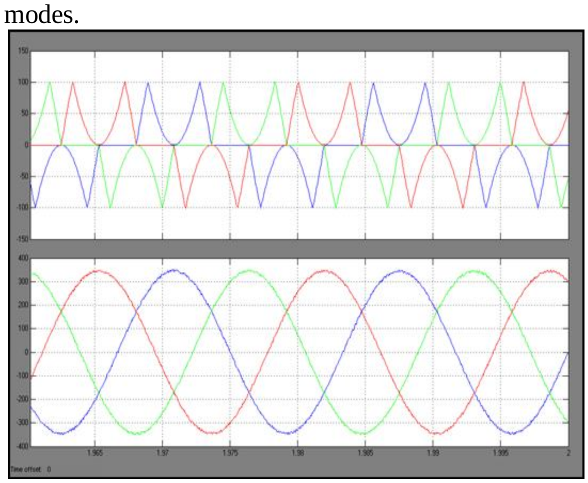


Fig.13. Zoom of the load currents and voltages produced by the DG with nonlinear load.

C. Islanding Mode Consideration

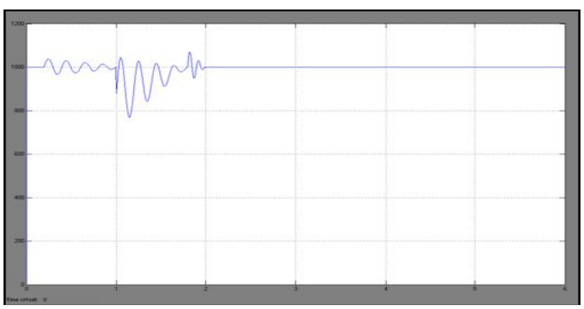
When a short-circuit occurs on the high voltage side of the DT, the protection devices closest to the event disconnect the grid from the distribution system in order to avoid stability problems [35], [36]. However, the DG remains connected, forming a local area whose mode of operation may be dangerous if the local load demand is greater than the power produced by the DG. To avoid this, the DG must identify the contingency as soon as possible and disconnect it from the local area. To understand the effects on the grid and power converters, the following series of events was performed. First, a balanced three-phase linear load demanding almost

25 kW was connected to the DG terminals at the beginning of the simulation.

At 1.8 s, the power produced by the DG system was reduced (p_{DC} drops from 125 kW to 100 kW), and a 75-kW threephase linear load was connected to the DG terminals to obtain a minimal power level exchanged with the grid, which, as reported in literature [11], is the most difficult situation to identify the islanding mode.Fig.14 identifies the effect of the islanding mode compared with the load connection or power transfer to the grid. In each case, the islanding mode did not affect the dc link voltage and power, or the ac power flow through the grid, which was not the case for the load connection or power transfer.

D. Islanding and Reconnection to the Feeder

Another important aspect of the DG operation is the islanding mode followed by a reconnection. As above, the test at the beginning of the simulations, a balanced three-phase linear load demanding 30 kW was connected to the DG terminals. The power produced by the DG system was reduced from 125 kW to 90 kW, and a 25-kW three-phase linear local load was connected 1.25 s after the simulated range started.



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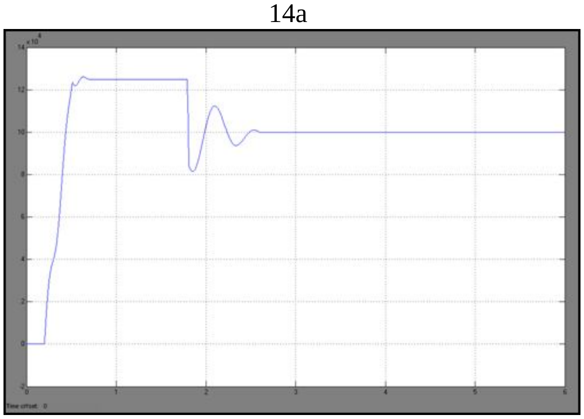

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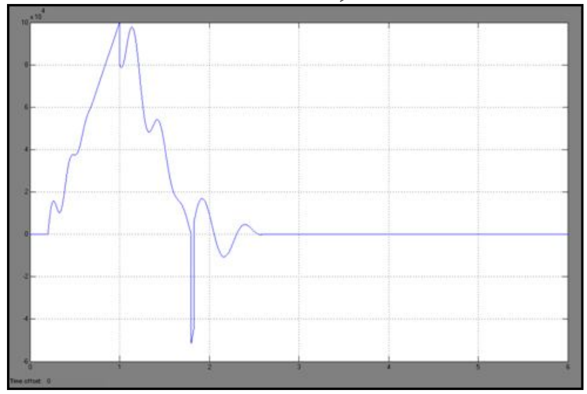

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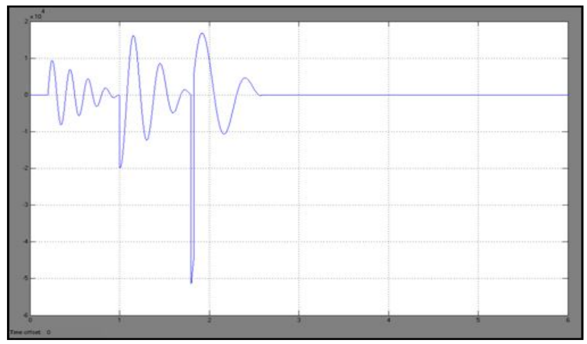
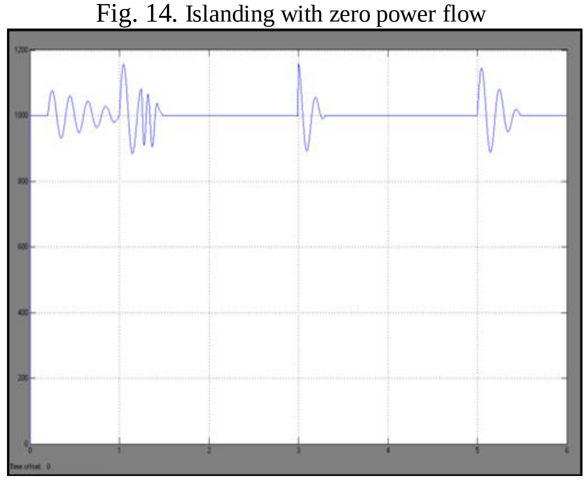


14d

Fig. 14. Islanding with zero power flow



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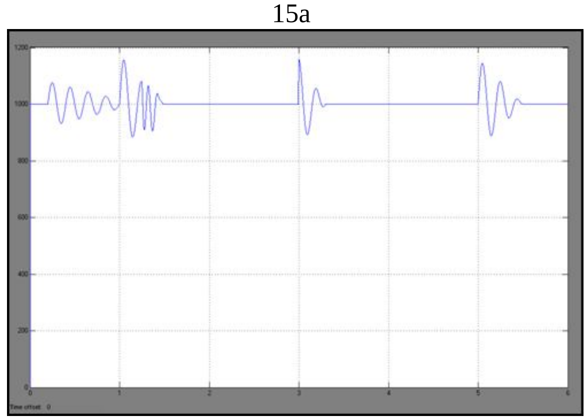

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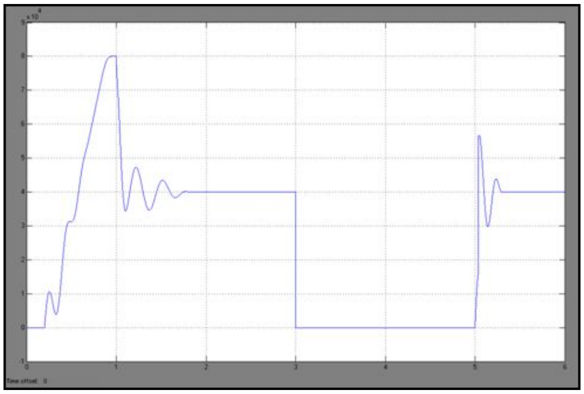

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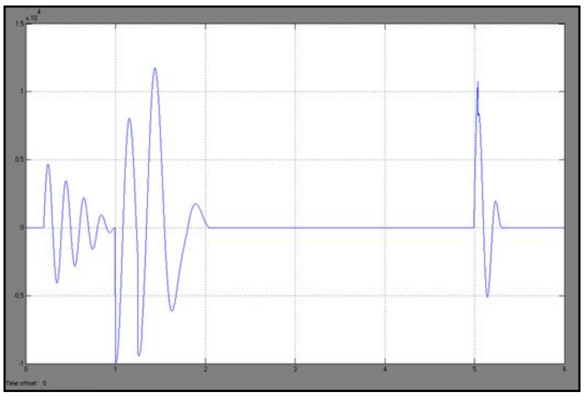

15d

Fig. 15. Islanding and reconnection with nonzero power flow. Performed here considers a limited power level exchanged with the grid.

The DG voltage amplitude was subsequently adjusted to exchange −10 kVAr with the grid. This was undertaken to obtain a minimal level of active (35 kW) and reactive (−10 kVAr) power through the grid, as seen in Fig. 15. Unlike what occurred in Section IV-C, the effects of islanding (at 3.0 s) followed by a reconnection [13] (at 5.0 s) were evident on the dc link voltage and power, or on the power flowing through the grid, with the most drastic case being the dc link power, which dropped to zero when the grid was reconnected.

VI. CONCLUSION

This paper presents another answer to connecting a decigram system to the grid, whereby the amplitude and displacement of the voltage synthesized by the decigram is regulated with relevance the grid voltage and therefore the management variable before and when the contingency is usually identical. to boot, a dc-dc increase device ANd a dc-ac VSI ar employed in a decigram system as an interface with the facility grid. The simulation and experimental results demonstrate that the association of decigram sources will have adverse effects, betting on the association procedures. to boost the decigram operation, the dc link voltage should be controlled, during this case by a dc-dc increase device. PI controllers related to resonant regulators were used as an answer to supply distortion-free decigram voltage, even once the native load is nonlinear or once distortion happens within the grid voltage. though the PLL rule tracks as quickly as potential, the frequency oscillations ar slowly damped attributable to the boundaries of amplitude.

APPENDIX I

To design the passive components of the step-up converter, the maximum current ripple (ΔI_{boost}), terminal voltage across the dc source ($\boldsymbol{V}_{RS}$) and dc link voltage variation (ΔV_{DC})(12) and (13) [16], [30], [37] must be considered. However, low impedance in the first and third harmonics have been used as design criterion for the output filter (14) and (15)[38], where f_D is the double of the rated frequency (120 Hz), f is the rated frequency (60 Hz), f_{SW} is the sampling or switching frequency (12 kHz), and X_{Lconv} and X_{Cconv} are the inductive and capacitive reactance of the output filter, respectively

$$C_{DC} = \frac{\Delta I_{boost}}{8 f_D \Delta V_{DC}} \tag{12}$$

$$L_{boost} = \frac{V_{RS}}{\Delta I_{boost} f_{sw}} - \frac{V_{RS}^2}{\Delta I_{boost} f_{sw} \Delta V_{DC}} \tag{13}$$

$$L_{conv} = \frac{XL_{conv}}{2\pi f} \tag{14}$$

$$C_{conv} = \frac{1}{2\pi f XC_{conv}} \tag{15}$$

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