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UNIVERSAL CONTROLLER FOR THE INTERCONNECTION OF DISTRIBUTED GENERATORS WITH UTILITY LINES AT CUSTOMER LEVEL VOLTAGES

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Abstract

This paper presents the design, construction and performance testing of a controller capable of protecting the utility from any negative side effect of the interconnection of distributed generation (DG) at customer level voltages. The controller is universal in the sense that it allows for the interconnection of all kinds of distributed generators: synchronous, induction and those that need a power electronic converter (solar, fuel cell, micro-turbine, *etc.*). The controller assures that the IEEE standards 1457 for the interconnection of DG and utility standards are complied. Additionally, the controller cuts the fault current in less than a cycle to prevent the increase to the short-circuit duty of the already installed protection equipment. This is especially important in the case of a synchronous interconnection in locations where the short-circuit power of the substation breakers is close to its limits. A 25 kVA utility grade prototype controller has been built and tested in the lab.

Key Words

Distributed generation interconnection, under frequency, over frequency, undervoltage, overvoltage, short-circuit current limiter

1. Introduction

Distributed generation (DG) is expected to play an increasingly important role in modern transmission and distribution systems [1]–[3]. DG offers many advantages to a distribution system. For example, bringing the generation closer to the point of consumption reduces the demand on the transmission and distribution systems while simultaneously reducing line losses. Properly controlled DG may provide support (voltage and frequency) during transient events. DG may provide localized power when the utility is out (island operation).

Despite the many advantages that DG may bring, there are several harmful side effects that DG can cause to the system, *e.g.*, voltage regulation problems. Both undervoltages and overvoltages are possible because most DG operators prefer to run DGs at unity power factor (or lagging power factor). Therefore, they do not contribute positively to the control of the voltage profile. All DGs, but perhaps more significantly, synchronously interconnected DG, increase the short-circuit duty of breakers. DG may create hazards to line workers because DG may not disconnect when the utility is out and cause back-feed into the grid. Most renewable DGs are not dispatchable, and if spinning reserve is reduced because of a large DG aggregation, the reliability of the system could suffer. Some DGs may disconnect during transients potentially producing a double contingency. Other DGs may inject harmonics and/or interact with other components of the system producing flicker.

An exhaustive literature review on DG interconnection is outside the scope of this paper. However, a review of the available published material related to the interconnection of DGs yields three types of documents: standards, scientific papers and reports on studies prepared for utilities.

The following standards were reviewed: (1) Family of the IEEE 1547-2003, which include 1547.1-2005, 1547.2-2008, 1547.3-2007, 1527.6-2010 (draft) [4]–[8] and are summarized in [9]; (2) Other IEEE standards required for the design of the controller, for example: IEEE 929-2000 [10] on photovoltaic systems and IEEE 519-1992 [11] on harmonics; Con Edison EO-2115 [12]. These standards establish the general requirements (voltage regulation, synchronization) for interconnection. They provide

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information and establish limits for the DG response to abnormal conditions (faults, voltage and frequency disturbances) as well as power quality (DC injection, harmonics). They also describe a wide range of issues associated with the interconnection of DG to the power system. Among the most important ones are: impact on step voltage regulation equipment; increased fault duty on circuit breakers; interference with the operation of protection systems; harmonic distortion contributions; voltage flicker; ground fault overvoltages; islanding; system restoration; power system stability; system reinforcement; and metering.

The Edison Electric Institute, Distributed Resources Task Force [13], has conducted a complete interconnection study that addresses system protection and coordination issues. The primary purpose of the protection system is to protect the utility from disturbances that can be caused by the DG and in cases where the DG operates under abnormal conditions. In this study, the effects of synchronous, induction and inverter-based generation are analysed. One important consideration, still under discussion, is the installation of a disconnect switch that is located next to the point of common coupling (PCC). The switch gives the utility the option to disconnect the DG from outside of the customer premises (in extreme conditions).

Recently, there have been advances in the interconnection technology of DG to the grid. For example, in [14] an interconnection strategy for wind turbine generators in a wind farm is presented. The issues of interconnecting large amounts of wind power in a feeder are treated in [15]. An algorithm to track the maximum point for photovoltaic (PV) cells is presented in [16], and the issues of interconnecting PVs are discussed in [17]. A multi-resonant frequency-adaptive synchronization method for grid-connected power converters that allows the interconnection of DG under distorted voltage conditions is given in [18].

This paper presents the design, construction and performance testing of a stand-alone universal controller that protects the utility from some of the negative aspects of interconnecting DG. In particular, the universal controller acts on under- and overvoltage, under- and over-frequency, harmonics and flicker. Additionally, the controller is capable of cutting the short-circuit current from the DG in less than one cycle, therefore effectively limiting the short-circuit current duty of breakers. The controller is also capable of distinguishing between inrush currents (caused by the connection of induction generators) and fault currents.

A utility grade (25 kVA) prototype has been built and tested against the current standards (IEEE and utility). Examples of abnormal operating conditions that produce tripping of the DG were reproduced in the lab to corroborate the proper operation of the controller.

There exist in the market protective relays that produce disconnection signals as per the IEEE Standards 1547; see for example [19]. However, these relays do not have a breaker (or a fast switch) integrated so that the actual disconnection is completed with the help of external devices.

There are, as well, publications describing other interconnection controllers similar to ours; see for example [20]. The uniqueness of our universal controller is its capability to disconnect the DG from the utility within a cycle during short circuits. Therefore, preventing the DG from contributing current to the fault allowing the use of synchronous generators even in locations where the breakers are close to its limits. Among the different available DGs, synchronous generators offer the best controllability (and provide the most advantages), as they can positively participate in the voltage-var and frequency-power control strategies of utilities.

Although in [20] the possibility of using solid-state switches is mentioned, mechanical switches were used which are not capable of cutting the short-circuit currents in less than one cycle. Additionally, this important feature of our controller has been fully demonstrated in the paper.

Another distinguishing feature of our controller is its ability to distinguish between the (normal) inrush current drawn by an induction generator at energization and short-circuit currents. This is important to prevent false tripping during the interconnection of induction-type DGs.

2. Controller Design and Implementation

The universal controller consists of three main systems: (1) the power circuit, whose main components are a set of fast-acting power electronics switches (thyristors) and two electromagnetic contactors; (2) the control system, whose central device is a digital signal processor (DSP) where the operating decisions are made; and (3) sensing instruments, such as current transformers and potential transformers, which enable the power and control subsystems to intercommunicate. The schematic diagram of the universal controller is shown in Fig. 1.

2.1 Power Circuit

Six thyristors (T11 to T23) are the main switching devices in the universal controller. These solid-state electronic devices were selected due to their fast switching characteristics. They are capable of interrupting short-circuit currents such that the duty of the circuit breaker at the substation is not increased. Thyristors can operate within half a cycle of a 60 Hz sine wave. This switch is controlled directly by the DSP.

Two contactors are used to provide physical isolation to the universal controller from the network on the utility and the distributed generator side. They are controlled by the DSP through a Darlington pair (DP) and an electromagnetic relay (ER) that supplies the coils (C1 and C2) of the contactors.

2.2 Monitoring Circuit

Three (one per phase) Hall-effect current transducers (CT1, CT2 and CT3) are used to measure the current supplied by the DG. Six resistive potential transformers (PT11 to PT23) provide reduced voltage measurements from both sides of the controller (utility and DG). Opto-isolators (OPT) are needed to protect the control circuit from the high voltage of the power circuit.

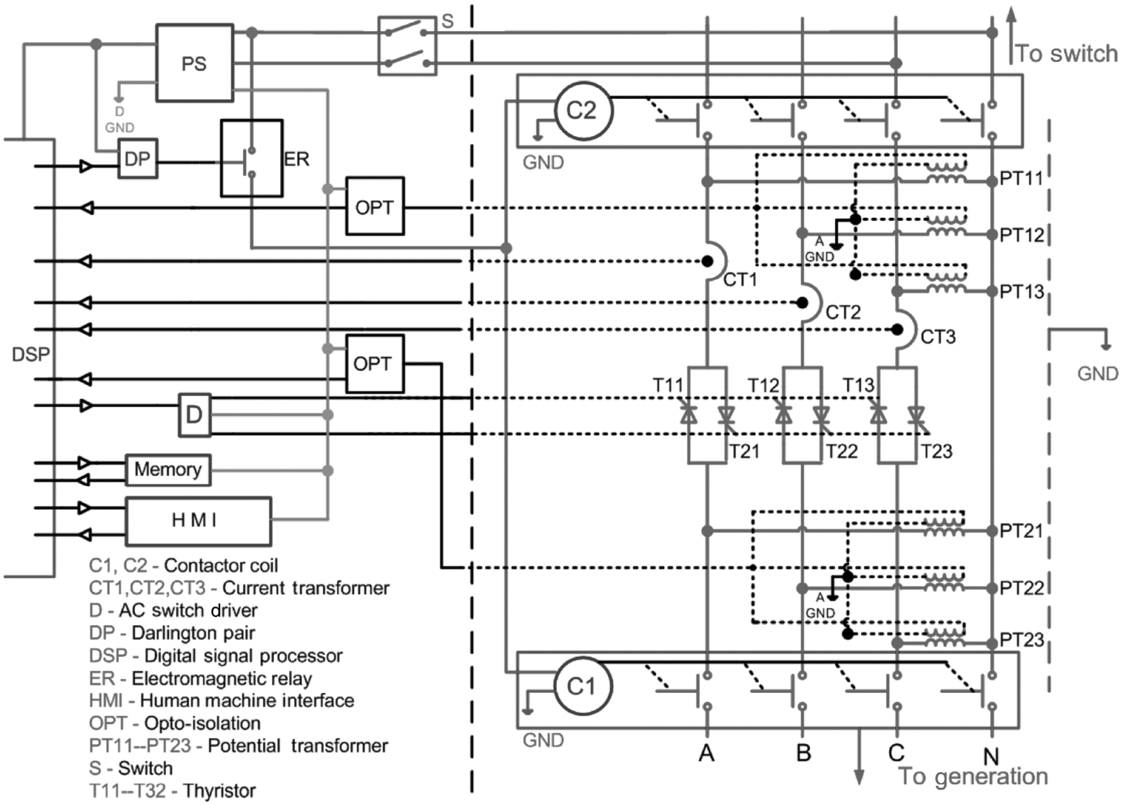

Figure 1. Schematic diagram of the universal controller.

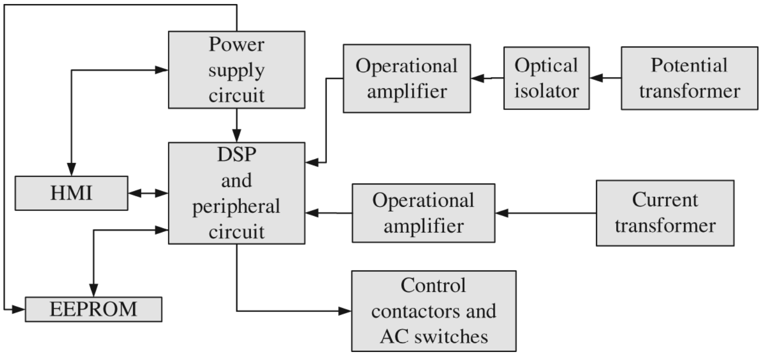

Figure 2. Diagram of the control circuit of the universal controller.

2.3 Control Circuit

As depicted in Fig. 2, the control circuit of the universal controller consists of the following components: the power supply circuit, a DSP with its peripheral circuits, a voltage signal sampling circuit, a current signal sampling circuit and the human–machine interface (HMI) circuit.

The power supply (PS in Fig. 1) feeds the control circuit and all the peripherals of the universal controller. It provides regulated +5 V, +12 V and 24 V. The DSP acquires signals from the voltage sampling circuit, current sampling circuit and the HMI circuit. It also controls the components in the power circuit (contactors and AC switch) by analysing the acquired signals.

The DSP's peripheral circuit contains capacitors, resistors and a crystal oscillator, which maintains DSP's working. The voltage signal sampling circuit in addition to the potential transformers and optical isolators uses operational amplifiers and on-chip (DSP) analog-digital converters. These circuits transform the voltages into the range that is accepted by DSP and convert them into numbers for use. The current signal sampling circuit contains current transformers, operational amplifiers and on-chip (DSP) analog-digital converter. Hall-effect current sensors transform current into a voltage signal. An operational amplifier changes the level of output voltage signal into the level accepted by on-chip analog-digital converter. The HMI circuit consists of an liquid crystal display (LCD) display, a dual in-line package (DIP) switch and an electrically erasable programmable read-only memory (EEPROM). The LCD displays the operation status of the universal controller, a selector switch sets universal

Table 1
Protection Features of DG Installation with Different Rating and Type

Power	Disconnect Switch	Under and Overvoltage	Under and Over-frequency	Synchronization Check	Phase Sequence	Dead Bus Reclosing	Anti-Islanding	DC Injection	Monitoring	Connection Status
<10 kW	Y	Y	Y	N(PV)	Y	Y	N	Y	N	
≤15 kW	Y	Y	Y	N(PV)	Y	Y	N	Y	Y	Y
(PV)	Y	Y	Y	N	Y	Y	Y	Y	Y	Y
≤30 kW	Y	Y	Y	N(PV)	Y	Y	Y	Y	Y	Y
≤50 kW	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
≤100 kW	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
≤250 kW	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
≤1 MW	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
≤2 MW	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y

controller work in different modes for different types of DG and EEPROM records the critical data when the universal controller disconnects the DG from the utility.

3. Interconnection Requirements

3.1 Types of Interconnections

As per the type of connection, DGs can be classified into three: (a) synchronous generator; (b) induction generator; and (c) inverter-based generator. Although there are similarities, the interconnection strategies need to be designed by type of interconnection. Additionally, in each group, there are differences that make the interconnection procedure different. Although the differences may seem subtle, they are very important for the successful operation of the DG. Table 1 summarizes the protection features that a DG installation must have according to standards classified by rating and type.

3.2 Synchronous Generators

For interconnection purposes, there are two categories of synchronous DGs: with and without closing device. For synchronous generators with closing device, the interconnection procedure is as follows:

1. The customer turns on the universal controller.
2. Contactors, C1 and C2, will be closed automatically.
3. The AC switch SW is turned on.
4. The customer turns the prime mover and synchronous generator.
5. The synchronizer makes the frequency and voltages of synchronous generator match with the voltage and frequency of the utility.
6. The closer detects synchronization and gives the order to the DG switch (DG SW) to turn on.
7. Once interconnected, the prime-mover controller will try to increase the speed so that the power supplied increases.
8. The universal controller monitors the DG voltages and currents and disconnects the DG from the utility if the conditions for generation are not right (SW turns off).

For synchronous generators without closing device, the connection procedure is as follows:

1. The customer turns on the universal controller.
2. Contactors, C1 and C2, will be closed automatically.
3. The AC switch SW is off.
4. The customer turns on the prime mover and synchronous generator.
5. The synchronizer makes the frequency and voltages of the DG match with the voltage and frequency of the utility.
6. The universal controller detects synchronization and turns on the AC switch SW.
7. Once interconnected, the prime-mover controller will try to increase the speed so that the power supplied increases.
8. The controller monitors the DG voltages and currents and disconnects it from the utility if needed (SW turns off).

3.3 Induction Generators

For interconnection purposes, there are two categories of induction DGs: induction generator with and without capacitor banks. For induction generators with capacitor banks, the interconnection procedure is as follows:

1. The customer turns on the universal controller.
2. Contactors, C1 and C2, will be closed automatically.
3. The AC switch SW is turned off.
4. The customer turns on the prime mover and the induction generator starts.
5. The universal controller detects if the direction of rotation is correct, if the slip is within the acceptable range, and turns on the AC switch SW.
6. The universal controller monitors the DG voltages and currents and disconnects it from the utility if needed (SW turns off).

For induction generators without capacitor banks, the interconnection procedure is as follows:

1. The customer turns on the prime mover and the induction generator starts.
2. The customer turns on the universal controller.
3. Contactors, C1 and C2, will be closed automatically.

4. The AC switch SW is turned on.
5. The universal controller monitors the DG voltages and currents and disconnects it from the utility if needed (SW turns off).

3.4 Inverter

Most of the residential PV systems are connected to the utility through a grid-tie inverter (also true for other DC sources). Grid-tie inverters cannot run on stand-alone applications. The procedure to interconnect this type of generator is as follows:

1. The customer turns on the universal controller.
2. Contactors, C1 and C2, will be closed automatically.
3. The AC switch SW is turned on.
4. The customer turns on the inverter.
5. The inverter performs its algorithm and starts supplying power.
6. The universal controller monitors the DG voltages and currents and disconnects it from the utility if needed (SW turns off).

4. Simulations

Transient simulations are carried out to design the control algorithm of the DSP. This allows for the controller to have relay function capable of discriminating between normal transient conditions (*e.g.*, energization inrush currents) and abnormal ones (a fault *e.g.*,). For the former no tripping signal should be generated, while for the later fast disconnection action is required. The case of the interconnection of an induction generator is discussed next.

When connecting an induction generator to the system, a short duration inrush current is drawn. Figure 3 shows the transient inrush current when interconnecting an induction generator with the utility. One can see that the duration of the inrush current is relatively short (0.05 s), but it has a value of 30 A, which is several times larger than the steady-state current. From the results of this simulation, one can tune the over current protection to discriminate between the inrush and fault currents. Figure 4 shows the transient of the interconnection of a synchronous generator.

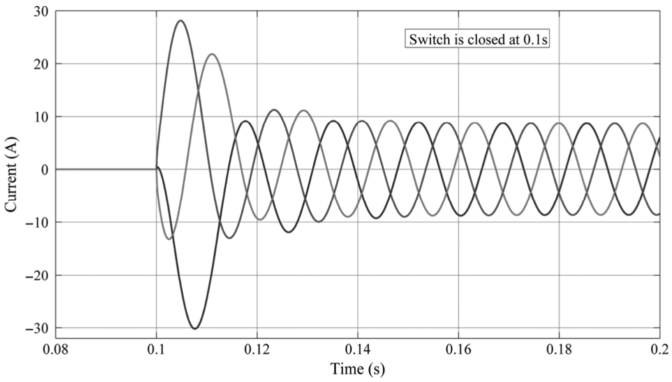

Figure 3. Inrush current simulation of the interconnection of an induction generator.

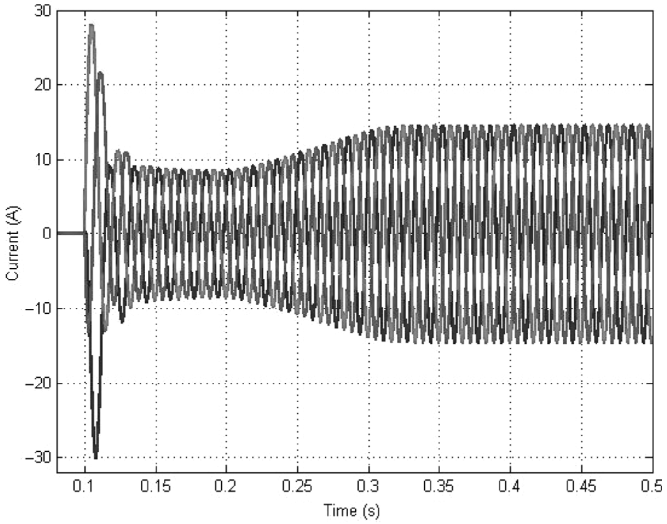

Figure 4. Simulation of the interconnection of a synchronous generator.

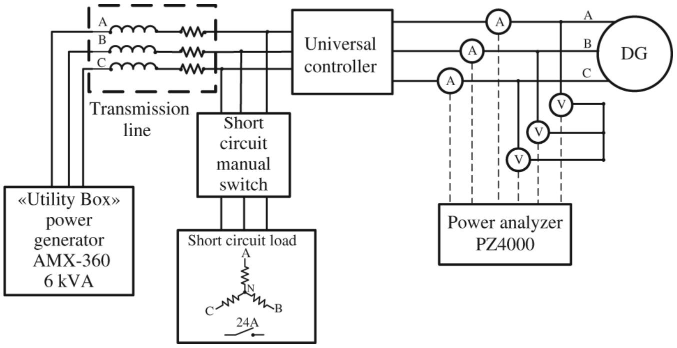

Figure 5. Experimental setup to verify the correct operation of all functions of the universal controller.

5. Test

A series of laboratory tests were carried out on a prototype of the universal controller to confirm its performance. Figure 5 depicts the experimental setup. A 6 kVA programmable power supply (Pacific Power AMX-360), capable of changing the voltage and frequency, is used to represent the utility in the experiments. A recording power analyzer (Yokogawa PZ4000) is used to capture the voltage, current and power of the different DGs under test.

5.1 Synchronous Generator

A synchronous generator and the electronic power supply that represents the utility are to be synchronized. They are both run at approximately the same frequency and voltage. The DSP checks the following conditions of utility and DG for synchronization: frequency difference within 0.3 Hz, voltage difference within 10% (as per IEEE 1547), phase sequence and phase angle difference within 20°. When everything is correct, the DSP gives the command to close the AC switch.

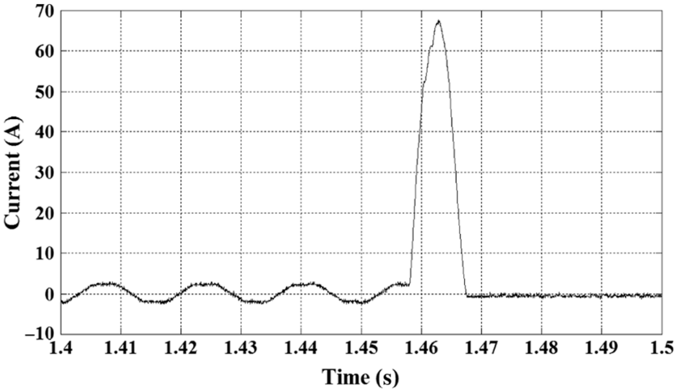

Figure 6. Plot of a current through the universal controller during a short-circuit test on a synchronous generator. The controller interrupts the current within one cycle.

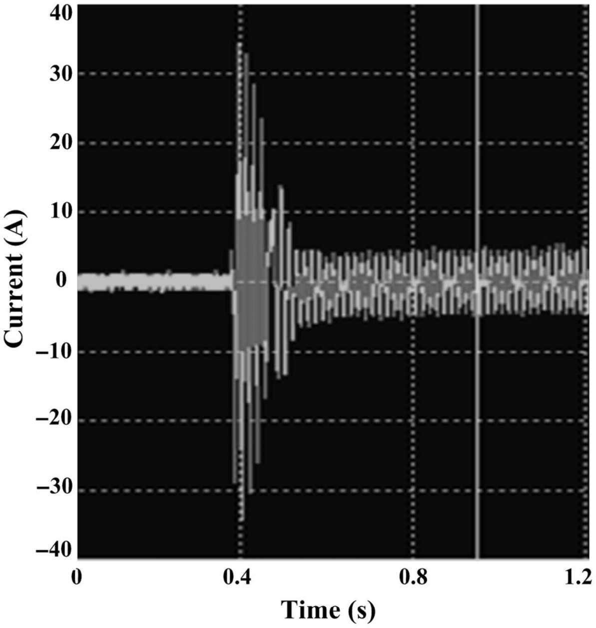

Figure 7. Inrush current plot during the connection of an induction generator.

After synchronization, the universal controller monitors the electrical conditions and disconnects the DG when any abnormality is detected. The following tests were performed in the lab to assess the correct performance of the controller:

1. The frequency of the electronic power supply (that simulates the utility) was changed to a value beyond the allowable range of frequency 59.3–60.5 Hz). We observed that the DSP instantly sends the signal to the switch, which opens at the next zero crossing.
2. The voltage of the electronic power supply (utility) is changed to a value beyond the allowable range of voltage (88–110%). We observed that the generator is quickly disconnected from the utility.
3. A short circuit is applied on the utility side. The DSP recognizes the abnormal operating condition and opens the AC switch. Figure 6 shows the recordings of this transient event. One can see that the universal controller successfully cuts the short-circuit current in less than a cycle. Therefore, the switch of the universal controller effectively shields the existing protection of seeing an increased short-circuit duty.

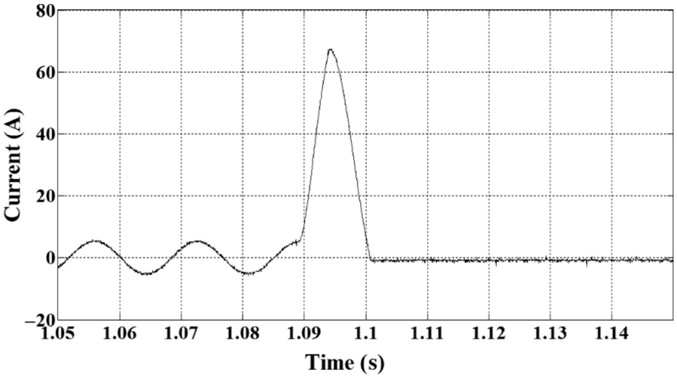

Figure 8. Plot of a current through the universal controller during a short-circuit test on an induction generator. The controller interrupts the current within one cycle.

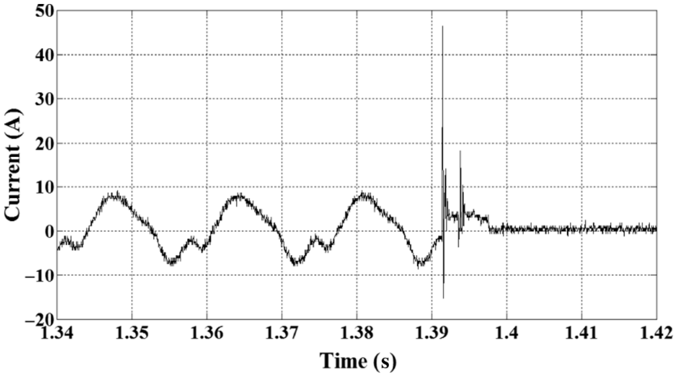

Figure 9. Plot of a current through the universal controller during a short-circuit test on an inverter-based DG. The controller interrupts the current within one cycle.

5.2 Induction Generator

The same tests (applied to the synchronous generator) were repeated for an induction generator. To connect the generator to the utility, the induction machine is run at synchronous speed. Then, the DSP checks the conditions for synchronization and when the utility provides "healthy" power (voltage in the range of 88–110% and frequency in the range of 59.3–60.5 Hz) gives the command to close the AC switch. The connection transient is shown in Fig. 7.

Next, the frequency of the electronic power supply is changed to a value beyond the allowable range of frequency (59.3–60.5 Hz). We corroborated that the induction generator is disconnected from the system. Subsequently, the voltage of the electronic power supply is changed to a value beyond the allowable range of voltage (88–110%) and we verified that the switch opens. Finally, a three-phase short circuit is produced at the terminals of the controller and its proper functioning corroborated. Figure 8 shows the current of this transient. One can see that the high fault current lasts for a little less than a half cycle.

5.3 Inverter

The battery of tests described above are applied to the inverter-based DG. A DC voltage source DG was synchronized to the utility through a grid-tie inverted. All functions of the universal controller were verified. The universal controller was very effective disconnecting the DG from the utility when abnormal conditions requiring disconnection occur in the utility. Figure 9 shows the recording of the short-circuit test at the controller terminals. It is observed that the controller disconnects the DG from the utility very fast.

6. Conclusion

The paper presents the design, assembly and testing of a utility grade, 25 kVA, universal controller to help mitigating the possible negative side effects of the interconnection of DG at customer voltage level. The controller can be used to interconnect any kind of DG including synchronous generators, induction generators and generators connected through power electronics devices (inverters). The controller is capable of protecting the grid, by disconnecting the DG, from the utility when abnormal operating conditions occur, *e.g.*, under- and over-frequencies, under- and overvoltages, harmonics and flicker.

A unique feature of the universal controller presented in this paper is that it is capable of cutting the short-circuit currents in less than a cycle. Therefore, making possible the integration of synchronous generators as DG because the short-circuit duty of the existing protective devices does not increase. The controller is also capable of discriminating between (normal) inrush and short-circuit currents. This is important for the interconnection of induction generators.

Laboratory experiments recreating several kinds of system anomalies have demonstrated that the controller can be used effectively to defend the grid from damaging side effects where DGs are involved.

References

[1] F.Z. Peng, Editorial–Special issues on distributed power generation, *IEEE Transactions on Power Electronics*, *19*(5), 2004, 1157–1158.

[2] P. Siano, L.F. Ochoa, G.P. Harrison, and A. Piccolo, Assessing the strategic benefits of distributed generation ownership for DNOs, *IET Generation Transmission and Distribution*, *3*(3), 2009, 225–236.

[3] G. Spagnuolo, G. Petrone, R. Teodorescu, M. Veerachary, and M. Vitelli, Guest editorial, *IEEE Transactions on Industrial Electronics*, *56*(11), 2009, 4307–4310.

[4] *IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems*, IEEE Std. 1547-2003, 2003, 1–16.

[5] *IEEE Standard Conformance Test Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems*, IEEE Std. 1547.1-2005, 2005, 1–54.

[6] *IEEE Application Guide for IEEE Std 1547, IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems*, IEEE Std 1547.2-2008, 2008, 1–207.

[7] *IEEE Guide for Monitoring, Information Exchange, and Control of Distributed Resources Interconnected with Electric Power Systems*, IEEE Std. 1547.3-2007, 2007, 1–158.

[8] *IEEE Draft Recommended Practice for Interconnecting Distributed Resources with Electric Power Systems Distribution Secondary Networks*, IEEE P1547.6/D7.0, June 2010, 1–35.

[9] T.S. Basso and R.D. DeBlasio, IEEE P1547-series of standards for interconnection, *IEEE Transmission and Distribution Conference and Exposition*, Dallas, TX, 2003, 556–561.

[10] *IEEE Recommended Practice for Utility Interface of Photovoltaic (PV) Systems*, IEEE Std. 929-2000, 2000.

[11] *IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems*, IEEE Std. 519-1992, 1992.

[12] Consolidated Edison, *Specification EO-2115: Handbook of general requirements for electrical service to dispersed generation customers* (New York, NY: Consolidated Edison, 2005).

[13] Interconnection Working Group, Murray Davis of Detroit Edison, *Distributed resources task force interconnection study* (Wasington, DC: Edison Electric Institute, 2000).

[14] S. Nishikata and F. Tatsuta, A new interconnecting method for wind turbine/generators in a wind farm and basic performances of the integrated system, *IEEE Transactions on Industrial Electronics*, *57*(2), 2010, 468–475.

[15] S. Sheng-Yi, L. Chan-Nan, C. Rung-Fang, and G. Gutiérrez-Alcaraz, Distributed generation interconnection planning: A wind power case study, *IEEE Transactions on Smart Grid*, *2*(1), 2011, 181–189.

[16] G. Petrone, G. Spagnuolo, and M. Vitelli, A multivariable perturb-and-observe maximum power point tracking technique applied to a single-stage photovoltaic inverter, *IEEE Transactions on Industrial Electronics*, *58*(12), 2011, 76–84.

[17] K.F. Katiraei and J.R. Agüero, Solar PV integration challenges, *IEEE Power and Energy Magazine*, *9*(3), 2011, 62–71.

[18] P. Rodriguez, A. Luna, I. Candela, R. Mujal, R. Teodorescu, and F. Blaabjerg, Multiresonant frequency-locked loop for grid synchronization of power converters under distorted grid conditions, *IEEE Transactions on Industrial Electronics*, *58*(12), 2011, 127–138.

[19] http://www.selinc.com/sel-700gt/.

[20] V. John, E. Benedict, and S.M. Danial, An universal interconnection system to connect distributed generation to the grid, *Inter. Conf. on Power Electronics, Drives and Energy Systems*, New Delhi, India, 2006, 12–15.

Biographies

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