PV BACK-UP SYSTEM TO RURAL CENTRES WITH WEAK GRID SUPPLY IN ALMERÍA. SPAIN. DYNAMIC ANALYSIS

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ABSTRACT: This paper presents a dynamic simulation and analysis of the "Sierra de María" photovoltaic system (Almería, South East of Spain), which consists of two identical subsystems with: 80 kWp photovoltaic array, 1176 kWh lead-acid batteries device, 150 kVA PWM inverter and 200 kVA six pulse rectifier.
The simulation and analysis of the whole photovoltaic "Sierra de María" system was made taking into account the dynamic models of photovoltaic array, battery system, inverter, rectifier and electrical network. An electromagnetic transients simulation program was employed
Keywords: Simulation - 1 : Off-Grid - 2 : Grid-Connected -3

1.INTRODUCTION

The system has a normal state of operation with the batteries charging from the electrical network during the night hours, the photovoltaic arrays connected to the electrical network during the sun hours and the batteries discharging to the network during the afternoon hours.
It allows other non normal states such as discharge of the batteries without network (autonomous mode) and the photovoltaic arrays connected to the batteries.

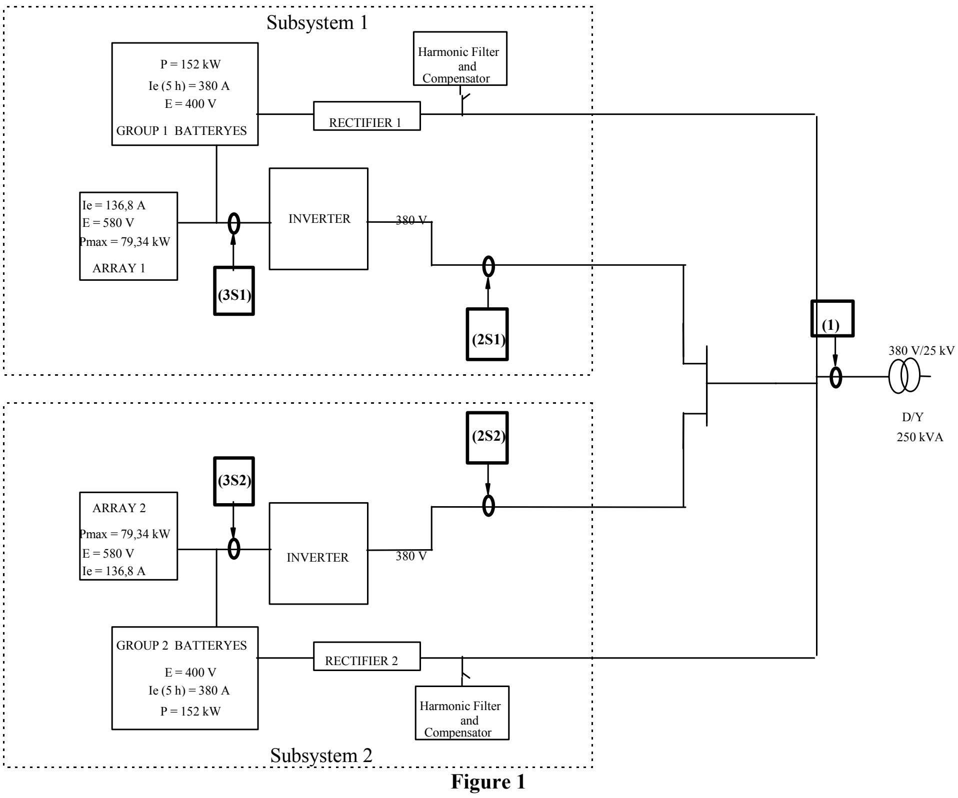

Figure 1

2.MODELS

2.1. The Photovoltaic Array has been modelled as a current source which is dependent on the voltage in terminals. The input parameters are radiation, temperature and voltage. The mathematical function which links the variables has been obtained from the real curves of solar cells. Radiation and temperature can be varied throughout the simulation

2.2.Single-phase PWM bridge inverters. Each branch has been modelled with an ideal switch in serial with a diode which includes the real characteristics of the IGBT, all this is in anti-parallel with a real power diode. The L-C filter for each single-phase converter has been designed in such a way that the PWM bridge control types, Stepp and adaptive Hysterisis bands, minimise the emission of high frequency harmonics

2.3.The orders of power, in the case of working with the network, can be independent for each subsystem and control tracking for the order is carried out independently for each of the 6 bridges, so that small unbalances in the network voltages can be allowed for. In the grid-disconnected working mode, one subsystem functions as master, in voltage source, following the voltage order specified at the connection point to the network feedback transformer, and the other subsystem works in current source mode, AHB modulation, the order has an intensity which is half the total at the transformer connection point. This working method will allow better functioning in the system faced with unbalanced charges

2.4.Rectifiers. 6-pulse rectifying bridges, with independent control according to each battery's state of charge. Design of harmonic filters for the 5th and 7th has been carried out for each bridge, with compensation. In the simulation, these compensation and filter groups can be connected/disconnected individually and independently for each subsystem

2.5. Battery. Given the short simulation periods, the battery has been modelled as a real voltage source with a serial resistance whose value has been obtained from the real charge and discharge curves for the batteries being used. The voltage value can be varied during the carrying out of the simulation

2.6.Network feedback transformer. The data have been obtained from vacuum and short-circuit tests on a real transformer. The real magnetisation curve is unknown, the simulations have been carried out with diverse values for X_{air}, 1 p.u. from 1 p.u.. to 6 p.u**,** this being a fundamental parameter in the start-up problems for grid-disconnected. The hysterisis phenomenon has not been considered

2.7.The mains network has been modelled as a three-phase voltage source, by means of single-phase sources in order to study the effect of network voltage unbalances on the system.

2.8.Charges. The single- and three-phase charges can be connected or disconnected throughout the simulation

3.GRID-DISCONNECTED

The main problem found when working is the simultaneous control of the system connection transient on the transformer and the charge

Subsystem 1 acts as a master in voltage source mode with PWM modulation. The order is to maintain the voltage at $230V_{rms}$ of phase. Subsystem 2 is the slave, in current source mode with modulation by Adaptive Hysterisis Bands. Its order is to achieve a parity current share between both subsystems.

At the moment of connection, only the master starts up, with the slave coming in to operation throughout the first cycle. The least desirable situation, when the slave comes in a cycle after the master, is developed below

3.1.Connection.

If the connection of a single subsystem were carried out on the no load transformer and at the nominal working voltage of that subsystem, a single current peak would be produced, which would rapidly be dampened

When the connection is carried out with the transformer charged at half the nominal charge, three current peaks are produced (figure 2). The first corresponds to the transformer connection and the following ones correspond to the control response of the subsystem on detecting the fall in voltage produced during the first current peak. It can be seen that the second current peak is of a greater magnitude than the first, the magnitude of the three connection peaks being greater than that obtained for the no load connection

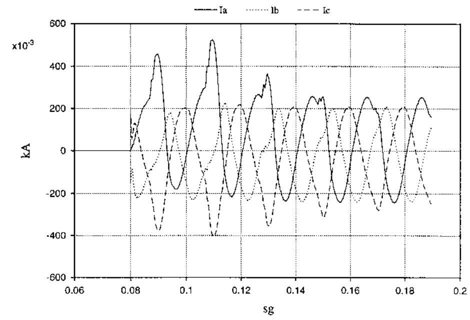

Figure 2. Measurement at point (1) of Figure 1

A ramp start-up has been opted for, starting with a voltage that corresponds to half of the nominal transformer voltage, and maintaining the voltage without modifying the order in the first three cycles of the connection, which correspond to the three current peaks studied earlier

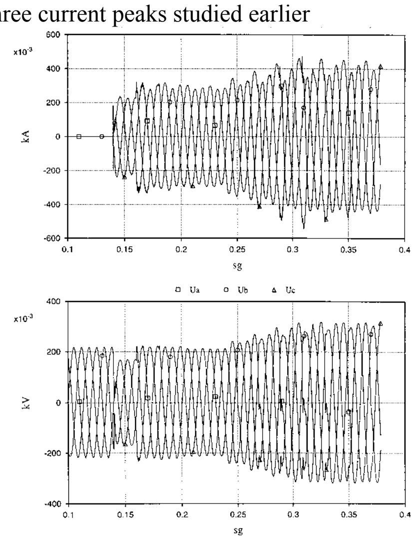

Figure 3. Measurement at point (1) of Figure 1

Figure 3 represents the currents and voltages at the connection point to the network feedback transformer, low side, and Figure 4 the currents in each subsystem. The non-existence of the of the aforementioned current peaks can be checked, as well as the fact that the currents corresponding to each subsystem are under the permitted maximums at all times. One can also see in this Figure how the slave subsystem starts up one cycle after the master, which means that the current peaks in the first start-up cycle are particularly damaging as they are borne entirely by the master subsystem

When control is carried out in such a way that the second subsystem steps in during the first cycle, the initial current peaks, when produced, are borne by both subsystems and the initial start-up voltage can be greater.

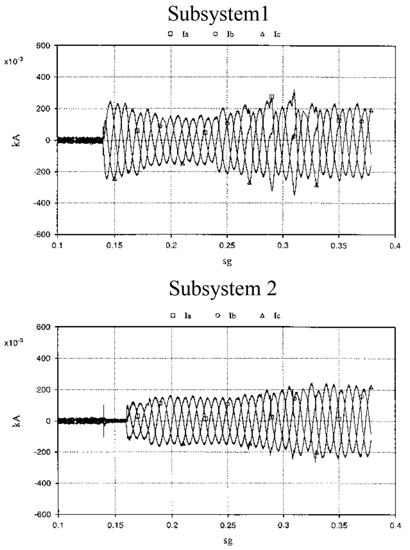

Figure 4. Measurement at points (2S1) and (2S2) of Figure 1

3.2.Sudden load variation

Another of the aspects to be studied is the system's response when faced with sudden variations in the connected load. If the load remains balanced, the most important parameter is the response speed. If the load becomes unbalanced, the most important parameter is the stability of the system, particularly the contents of the second harmonic of the direct current in the battery or the photovoltaic field.

3.2.1.Three-phase load variation

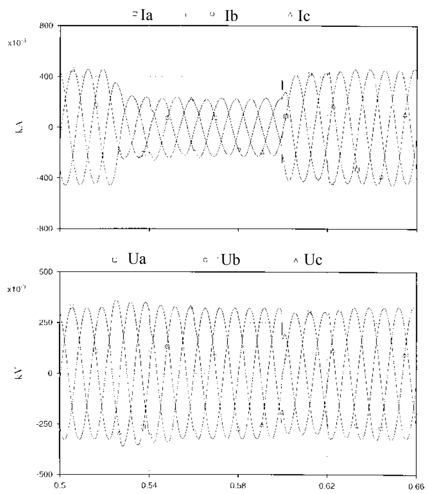

Figure 5. Measurement at point (1) of Figure 1

Figure 5 shows the system's response when faced with a sudden disconnection of 50% of the nominal load, t=0,52sg, and the reconnection of this load at t=0,6sg the currents and voltages in the network feedback transformer, low side. It can see that the system's response is immediate, and how, in two cycles, 0.04secs, it goes into permanent rate

On load disconnection, an overvoltage is produced in the first cycle which is quickly decreased by the control.

The opposite phenomenon is produced in the reconnection of three-phase load: voltage drops slightly in the first cycle, recovering to practically nominal value in the second cycle after connection

The harmonic contents of the battery currents for both subsystems are presented in Figure 6. There is a DC component which is exactly the same for both subsystems, (310 A), and harmonic components from the commutation frequency range (10kHz). No low frequency components appear as the three phases of each subsystem are balanced

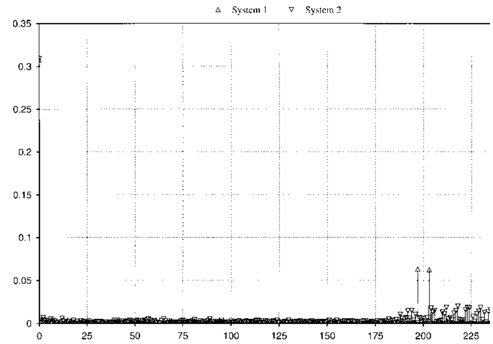

Figure 6. Measurement at points (3S1) and (3S2) of Figure 1

3.2.2.Single-phase load variation

The system is going to allow large unbalances in load for short periods of time. The main problem is not one of instability in the feedback with the load, but rather the fact that the unbalances in load are going to produce a greater level of harmonics in the DC current: a situation which is not recommendable over prolonged periods of time

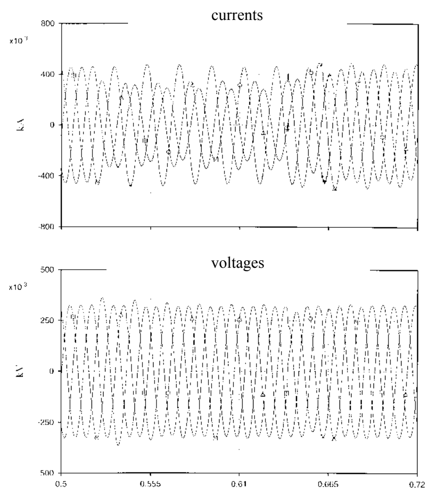

Figure 7. Measurement at point (1) of Figure 1

Figure 7 shows the currents and voltages at the connection point of the transformer, low side, for a load unbalance in phase **a** of 50% with respect to the nominal one. It can be seen how the system control acts rapidly on the initial overvoltage at the moment of load decrease in the phase, with no large overvoltages or overcurrents in any of the phases. 6 cycles after the disconnection, load reconnection in phase **a** is produced, and the voltages are quickly stabilised

Figure 8 shows the study of the harmonics contents for the DC currents, where harmonic components of 100Hz appear in both subsystems, the master subsystem being of the order of a third of the DC component. In this paper a frankly unfavourable case is presented with a 50% unbalance in the nominal load, which should not have to be borne by the system for prolonged periods of time. Other load unbalances of a lesser proportion can be assumed.

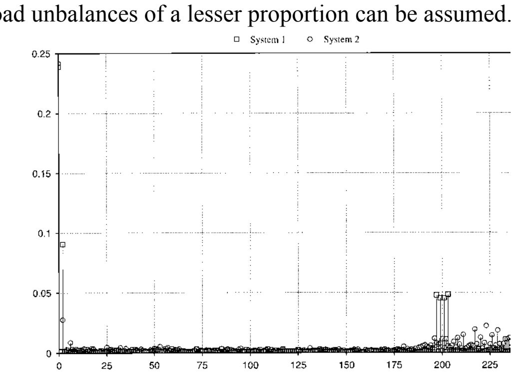

Figure 8. Measurement at points (3S1) and (3S2) of Figure 1

4.GRID-CONNECTED

Both subsystems work in current source mode with modulation by Adaptive Hysterisis Bands. The order to be followed is to inject a specified power to the grid, S = P+jQ. In this paper the order to be followed is considered to the injection of exclusively real power, with an equal share for both subsystems

The control models used allow the power orders for both subsystems to be different, due, for example, to an unequal load state in the batteries, and the variation of orders can be carried out through a ramp or suddenly.

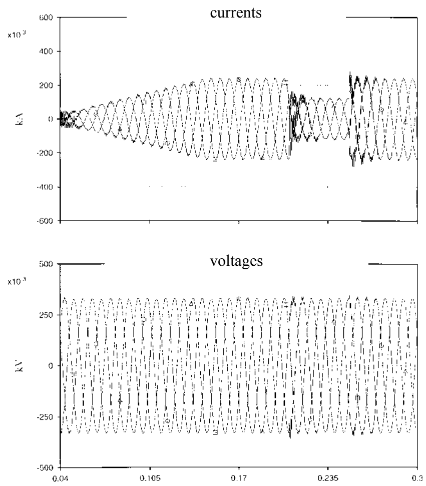

Figure 9. Measurement at point (1) of Figure 1

In the system start-up it has been found that the method which produces the least distortion is the ramp**,** with the system being able to modify the power orders suddenly once it reaches the permanent rating. This is reflected in Figure 9. The system has been taken from the initial state of practically nil power to nominal power, following a power order that increases according to a *gradient* in less than 10 cycles of the network signal. Once the permanent rating is reached the power order injected into the network has been modified suddenly to half the nominal power.

The current distortion during the ramp start-up is practically nil, except in the first connection cycle. However, rapidly dampened distortions are produced when faced with very sudden variations in the power order

5.CONCLUSION

The Sierra de María Photovoltaic Power Plant has been modelled by means of an electromagnetic transients analysis programme. Likewise, the two PWM modulations have been programmed to be used for the on/off control of the IGBT's of the inverter, Stepp and Adaptive Hysterisis Band bridges, as well as the two forms of working, grid-connected and grid-disconnected.

What has been obtained is an efficient method of predicting how the system will respond when faced with variations in any of the parameters, load, network voltage, control orders, connections, disconnections, which allows optimum functioning of the various control methods to be checked a priori..

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