Paper accepted for presentation at 2009 IEEE Bucharest Power Tech Conference, June 28th - July 2nd, Bucharest, Romania

Optimum Control for an Autonomous Micro Hydro Power Plant with Induction Generator

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Abstract--**This paper deals with the voltage and frequency control of an autonomous induction generator (IG). In order to do that, a voltage source inverter (VSI) with a dump load (DL) circuit on its DC side is employed. The IG frequency is controlled by keeping constant the VSI synchronous frequency. For the IG voltage regulation two cascaded regulators are used, which have as reference the line voltage and the VSI DC voltage, respectively. Then, the DL is replaced with a Storage Device (SD) consisting in a bidirectional DC/DC converter and a battery bank. Simulations and experiments are carried out in order to investigate the reliability of both configurations.**

Index Terms— **DC/DC power conversion, energy storage, frequency control, induction generator, hydroelectric power generation.**

I. INTRODUCTION

THESE days there is a growing concern regarding the impact of using energy sources based on fossil fuel for electricity production, on both environmental and economical markets. Furthermore, the Kyoto protocol stipulates by 2010 a gradual diminution of polluting gases that each covenanter state releases into the atmosphere. Relying on these two aspects, the need for green energy arises; as fossil fuel based electric energy production is still a major polluter worldwide.

In Romania, energy production from renewable sources is based mainly on hydro power plants, as the hydrographic network offers a large unexploited potential for micro and small plants.

For stand-alone low power systems based on micro-hydro, the induction generator (IG) is the most suitable, due to the following advantages over the synchronous one: price, robustness, simpler starting and control. On the other hand, this mode of operation is dependable on the prime – mover speed, capacitor and load. Thus, proper regulators for both voltage and frequency must be employed.

The system active power circulation gives the frequency value. To keep constant the frequency it is necessary to keep the active power constant at its rated value. As the loads are variable by nature, the equilibrium cannot be maintained without a regulating device. The balance can be reached by adjusting the input mechanical power. However, such a solution implies a speed governor for the water turbine. The mechanical adjustment is slow; it produces high mechanical and hydraulic stress and is less reliable.

Another solution is to use an electronic load controller [1], adding an additional load in the circuit, in order to maintain the total load constant. A power electronic controlled resistor is employed as dump load. The control circuit is switching the dumping load in such a manner that the sum of the instant load and the equivalent dumping load remains always constant and equal with the total rated full load.

The voltage control is requiring a reactive power balance in the network. The regulating devices are mainly based on voltage source inverters (VSI) [2]. A STATCOM can be used to control the reactive power and to ensure harmonics compensation [3].

II. SYSTEM CONFIGURATION

For frequency regulation a voltage source inverter (VSI) connected in parallel with the IG is used. The VSI operates at constant synchronous frequency (f_n=50Hz), maintaining the system frequency constant, excepting the start-up [4]. On the DC side of the VSI there is a capacitor -C_{DC}- and a circuit which manages the exceeding power.

Thus, the system's power balance is reduced to the DC capacitor voltage control. For this, two control possibilities are proposed.

The first one implies the use of a dissipative circuit also called dump load (DL). It consists in a DC chopper and a dumping resistance. The active power that is not consumed by the loads circulates through the VSI towards the DL, where is transformed into heat. It can be used for water and household heating. The main advantage of this first solution is its simplicity (only one semiconductor device to control).

This work was supported in part by the Romanian Education Ministry through contract 11004/2007.

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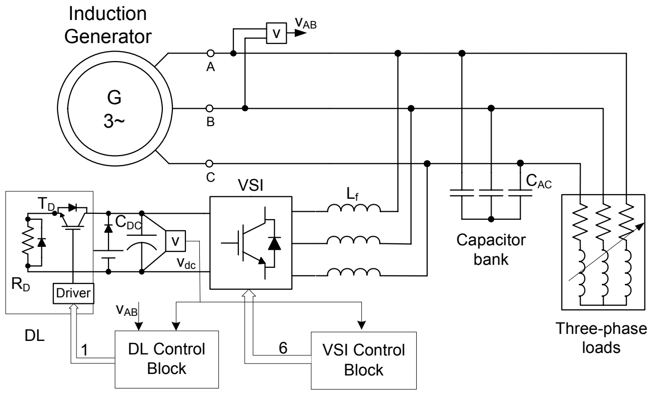

Fig. 1. Circuit diagram of the proposed topology using the VSI+DL combination

The other solution for voltage control is to replace the DL by a storage device (SD). It consists in a buck-boost bidirectional converter along with a bank of lead acid batteries. The exceeding active power is used to charge the batteries. When, due to some particular reasons, the generator power is not enough, the energy from the batteries will supplement the loads through the VSI (the main advantage over the DL circuit). The storage system also ensures the starting process of the IG, supplying the initial DC voltage.

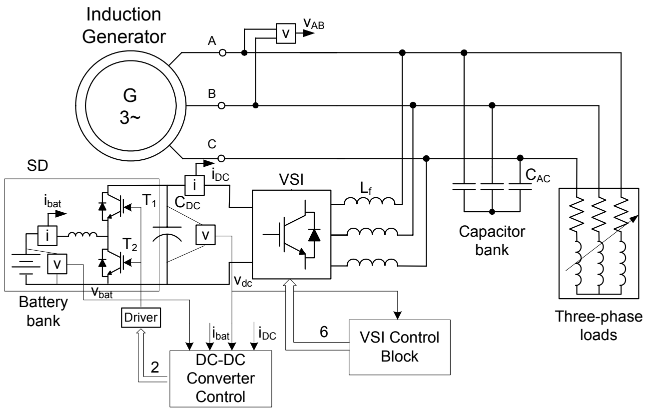

Fig. 2. Circuit diagram of the proposed topology using the VSI+Storage combination

III. THE CONTROL SYSTEM

A. DL Control

The dump load connected to the VSI DC side will be controlled so that the voltage across the C_{DC} capacitor remains at a constant level, maintaining the system voltage in a standard variation range.

Thus, the difference between the power delivered by the IG and the loads demand will circulate through the VSI towards the C_{DC} capacitor, which acts as a short-time energy storage element. The DC voltage variation ratio depends on the capacitance value and on the amount of power transferred from the IG towards the capacitor. The capacitor value plays a very important role during transitory regimes, when it has to handle large amounts of energy (in or out).

Two PI controllers are used to regulate the system voltage, as shown in Fig. 3. The first PI controller is the leading voltage regulator. It compensates the voltage drops across the inverter arms and filter, IG leakage impedances, and other circuit elements, which usually led to a decrease of the IG voltage. The IG root-mean-square (RMS) voltage (V_{AB}) is the feedback signal, it is compared with the 230 V reference signal (V_{REF}), and the error feeds the PI controller, giving the reference signal (V_{DCref}) for the second controller. The second PI is used to maintain constant the C_{DC} voltage. The allowed voltage variation (ripple) across C_{DC} capacitor (ΔV_{DC}) will give the frequency and the width of the pulses that drive the T_d transistor from the dump load.

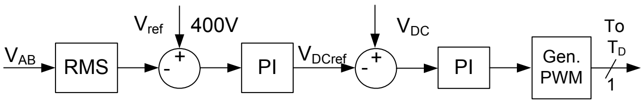

Fig. 3. The DL control strategy

B. SD Control

The storage device consists in a bank of batteries connected in series and buck –boost bidirectional converter. The last one is used in order to ensure the interface between the VSI DC capacitor and the battery bank and to allow a rapid exchange of power in both directions between the two sides. The DC/DC converter control consists in generating the driving pulses for its two transistors.

The control strategy (see Fig.4) is also based on the DC capacitor voltage variations. When the power flows form the IG through the VSI towards the batteries, this voltage tends to increase. Otherwise, it decreases.

First, the generated power is compared with the consumed one. The resulting power is divided by the battery voltage V_{bat} in order to obtain the battery reference current I^*_{bat}. This current is compared with the measured one, the error being the reference signal for a PI controller. The PI controller output is subtracted from the battery voltage, resulting the converter voltage necessary to achieve I^*_{bat} current. Finally, the duty cycle for the PWM generator that gives the driving pulses for the two transistors is obtained.

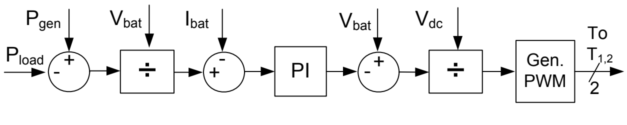

Fig. 4. The DS control strategy

IV. SIMULATIONS AND EXPERIMENTS

The reliability of both control configurations is tested through a series of simulations and experiments. The modeling and simulations were made under the Matlab/Simulink environment. The configuration includes a

2.2kW IG, a block that models the prime mover (hydraulic turbine), the VSI and DL/SD, an capacitor bank, loads and measurement blocks.

The experimental setup consists in a 2.2 kW three phase induction generator, driven by a 3kW induction motor which emulates a hydraulic turbine (with the use of a DS1102 system from dSPACE). Data acquisition and system command is ensured by a dSPACE 1103 control board.

A. VSI+DL topology

The generator is driven in order to obtain at its ends an active power of around 1500W. At this moment, there is no load connected at the IG leads. The active power flows through the VSI and is consumed by the DL circuit. At t=2s, a resistive load of 900W is connected in the system, being disconnected at t=3.5 s.

From the waveforms below it can be seen that the control system reacts promptly in order to mitigate this transitory regime. The voltage and frequency variations are insignificant, ensuring a high degree of stability for the proposed configuration. The frequency variation is depicted in Fig.5, while the RMS line voltage in Fig. 6.

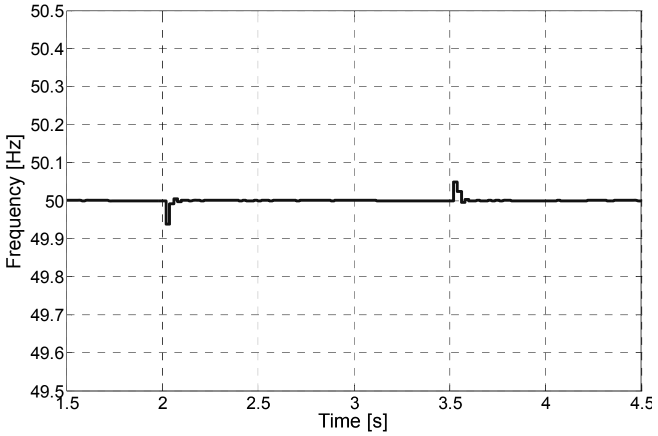

Fig. 5. The frequency variation during transients (simulations)

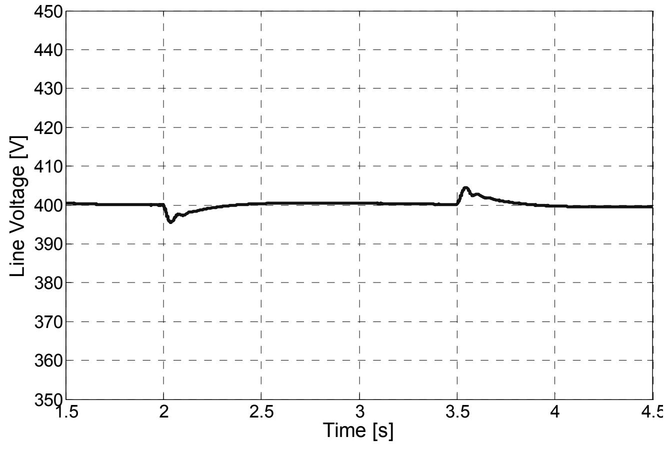

Fig. 6. The IG RMS line voltage variation for a 900W load transient (simulations)

The experiments follow accurately the situation from the simulations, only that the 900W load is connected at t=2.1s and disconnected at t=5.4s. The results are similar, as the voltage and frequency variations do not exceed the power quality standards. In Fig. 7 the RMS line voltage is depicted. When the resistive load is connected, at t=2.1s, the line voltage has a sag, decreasing to around 375V, but is rapidly brought back to the rated value by the voltage regulator. The same fast response can be seen when the load is disconnected. The frequency variations, as resulting from Fig. 8, are also insignificant.

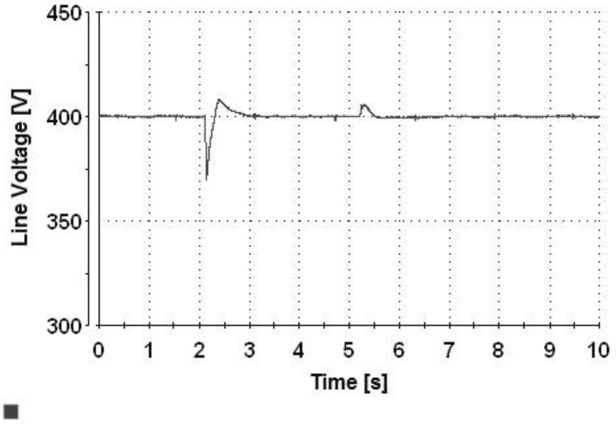

Fig. 7. The IG RMS line voltage variation for a 900W load transient (experimental)

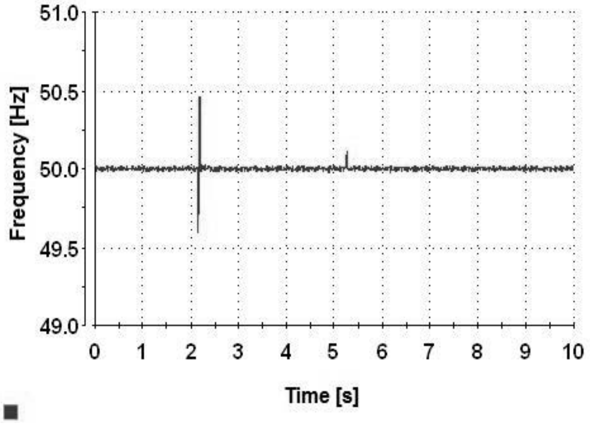

Fig. 8. The frequency variation during transients (experimental)

From the results presented above, it can be seen that the VSI+DL combination ensures a high degree of stability during transitory regimes. But when the load demands are higher then the generator can produce, power quality issues appear. For example, the following case is studied: the IG produces around 1500W and supplies a 900W load. At t=2.5s, another 900W load is connected to the system. In this situation, the following phenomena occur: as the VSI operates at 50Hz, the frequency is not influenced by this sudden load change (having quite the same variation as in Fig. 5). By contrast, the RMS line voltage decreases significantly and stabilizes around

360V (see Fig. 9). The VSI DC side current is shown in Fig. 10. After the 900W load is connected, this current becomes negative for a short period of time (around half a second), as the large DC capacitor acts as a short time energy storage device. But this is not sufficient and the DC current goes to zero.

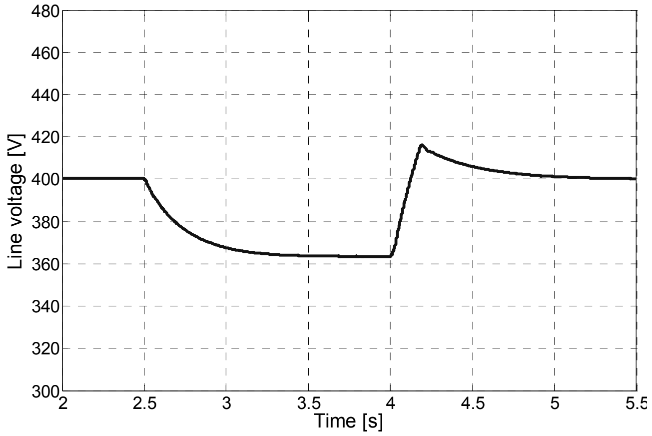

Fig. 9. The IG RMS line voltage variation for a 900W load transient (simulations)

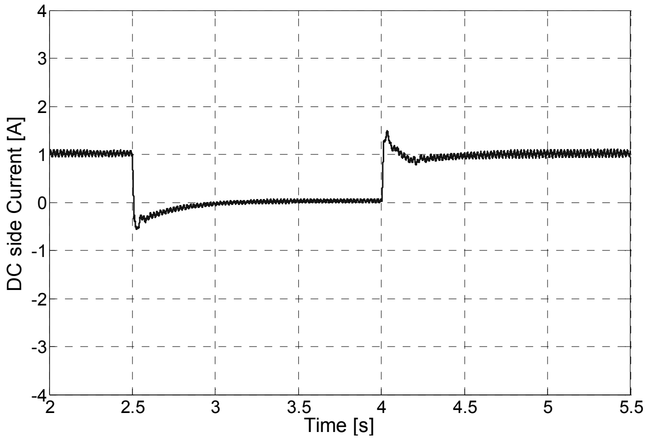

Fig. 10. The VSI DC current variation for a 900W load transient (simulations)

From here results the main disadvantage of this configuration, as it cannot handle the situations when the demanded power is higher then the generator can produce. For this reason, the decision of replacing the DL circuit with a Storage device was taken.

B. VSI+SD topology

The same operating conditions were considered also for the VSI+SD combination. Here only simulation results are presented. The system response to the 900W resistive load connection is given in Fig 11-14. The voltage and frequency deviations (see Fig. 11 and 12) during the transitory regime are very similar with the one obtained with the VSI+DL configuration.

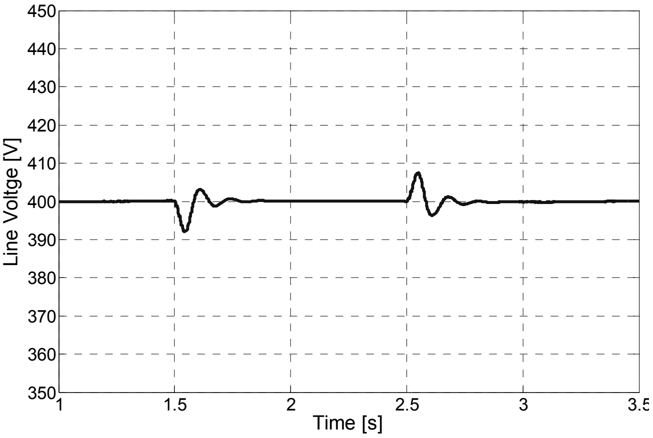

Fig. 11. The IG RMS line voltage variation for a 900W load transient (simulations)

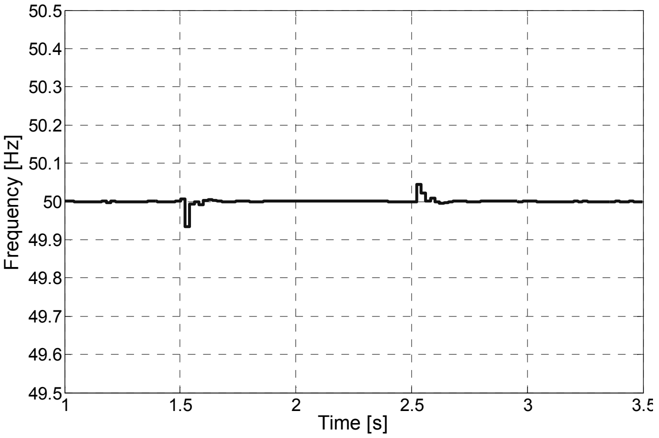

Fig. 12. The frequency variation during transients (simulations)

As the entire produced power flows through the VSI towards the batteries (before the load connection), the VSI DC current is around 2.5A. At t=1.5, after the 900W load connection, this current decreases to 1A, reflecting the decrease of energy flowing through the converters. At t=2.5, when the load is disconnected, the current returns to its initial value (see Fig. 13). This change in the current value can be noticed on the battery side. When there is no load connected, the 28A charge the batteries. After the load is connected, the charging current decreases proportionally with the load value to 10A, as can be seen in Fig.14.

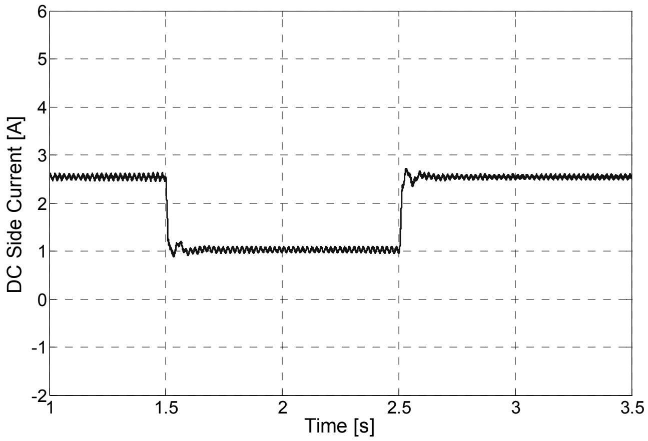

Fig. 13. The VSI DC current variation for a 900W load transient (simulations)

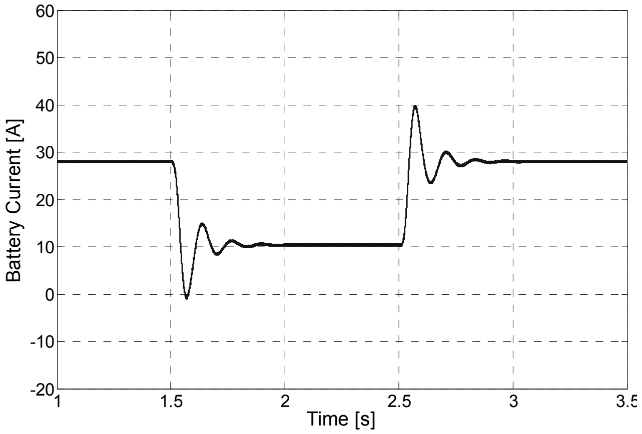

Fig. 14. The battery current variation for a 900W load transient (simulations)

Next, the system response to a higher energy demand is analyzed. In consequence, the situation when, besides a 900W load permanently supplied by the generator, another 900W load is connected and disconnected, at t=2.5s and t=4s respectively. In this case, the voltage and frequency variations are very similar to the ones depicted in the precedent studied case and are not depicted. Of real importance are the VSI DC current and the battery current, shown in Fig. 15 and 16. After the additional 900W load connection, the VSI DC current changes its sign, from 1A to -0.5A, so the power is now flowing from the batteries, through the DC/DC converter and VSI, supplying the difference of power that the generator cannot give. Thus, the battery bank passes from charging to discharging mode, as the current value changes from 10A to -8A.

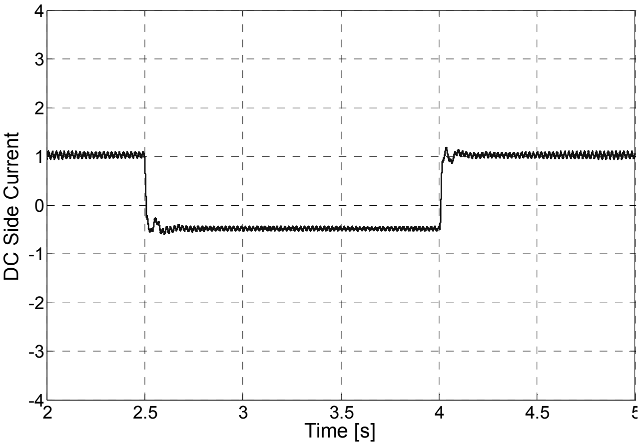

Fig. 15. The VSI DC current variation for another 900W load transient (simulations)

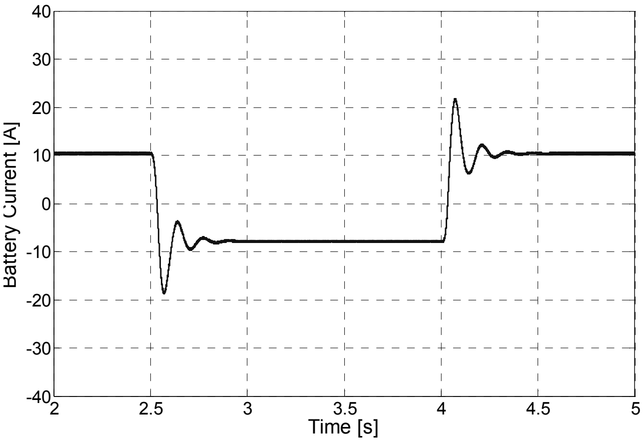

Fig. 16. The battery current variation for another 900W load transient (simulations)

The results depicted above show that this second topology provides the same good results in terms of system stability as the VSI+DL combination. As only simulation results were shown for the VSI+SD topology, the experimental validation will be subject of a future paper.

The advantage of the VSI+SD control topology arises from the fact that it can sustain the system through periods when the energy demand exceeds the production. The length of these periods is dependable on the storage capacity of the SD.

V. CONCLUSIONS

The aim of this paper was to make a comparison between two topologies used to ensure the stability of a stand-alone system supplied by a small power induction generator. Both the VSI+DL and VSI+SD topologies showed satisfying results in terms of ensuring the system stability. But when the demanded power was bigger then the produced one, only the VSI+SD topology could sustain the system. The opportunity of using one of these control topologies relies on site specificity and energy quality demands.

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VII. BIOGRAPHIES

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