Reliability studies of a PV-WG hybrid system in presence of multi-micro storage systems

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Abstract— **In the last years, distributed generation (DG) and microgrid (MG) technologies have been used to moderate the stress due to main stream utility grid electricity demand increase. The dispatch of renewable distributed energy sources at present is performed in such a way that, when implemented at very large scale, their intermittency can impact on the grids, what leads to concerns in terms of power quality and of reliability of supply. In this paper the attention is focused on MG reliability. On this subject the authors have proposed, in previous papers, opportune configuration schemes of MG constituted by a photovoltaic plant, a Wind plant and an Uninterruptible Power Supply. The goal of this paper is to evaluate the reliability improvements of load supply against network congestions adopting the proposed hybrid configurations in presence of storage systems for each energy source proposing an opportune operating strategy for the energy control system. In particular, the reliability estimation is performed in terms of the number of the critical loads interruptions and in particular of the charge state of storage systems, over a certain period of time by using the Monte Carlo simulation method.**

Keywords-component: Photovoltaic plant, Reliability analysis, Renewable sources, UPS, Wind plant.

I. INTRODUCTION

MICROGRIDS (MG) are becoming a reality in a scenario in which renewable energy, distributed generation (DG), and distributed storage systems can be embedded into the grid. These concepts are growing up due to not only environmental aspects but also due to social, economical, and political interests. The variable nature of some renewable energy systems such as photovoltaic or wind energy relies on natural phenomenon like the sunshine or the wind. Consequently, it is difficult to predict the power that we can obtain through these prime sources, and the peaks of power demand do not coincide necessarily with the generation peaks.

Hence, storage energy systems are required if we want to supply the local loads in an uninterruptible power supply (UPS) fashion [1-3]. Some small and distributed energy storage systems can be used for this purpose, such as: flow batteries, fuel cells, flywheels, superconductor inductors, or compressed air devices.

The MG is able to operate with only a small power exchange with the rest of the power system and at time it can be disconnected from the main network system and operate in islanded mode. And, when there is a utility failure, the microgrid still can work as an autonomous grid [4-5].

In particular, in [6-7] it has been to develop a MG able to join the DG benefits to the UPS reliability characteristic. In particular, in a previous paper [6] the authors have proposed a novel configuration of electrical system in which a photovoltaic (PV) plant is interconnected with an UPS. Moreover, in [8], the authors, considering the financial incentives regarding the electric generation by wind power (WG), have take into account also the presence of a mini WG plant (< 1MW) as other available source to supply the critical loads.

In this paper the attention is focused on the reliability of this hybrid MG configuration. In particular, reliability is defined as the measure of the continuity of load supply (that is how long supply to the customer is interrupted). In other words Reliability and Continuity of Supply is the measure of the availability of supply at the customer's point of supply. Supply is said to be reliable if they are very few or no interruptions in a given period.

From the above considerations, the aim of this paper is to evaluate the reliability load supply improvements adopting the proposed configuration of PV-WG power park, proposed in [8], taking into account the presence of storage systems for each energy source adopting an opportune operating logic for the energy control system. The main control is used at the top level to make high level decisions for economic dispatching evaluating the energy availability for each energy source by providing the appropriate control operation to the second level source controllers. At the second level the controllers are regulating the individual energy source unit in order to supply the total load energy request and reduce the energy change with the network system.

At this scope firstly in the section II the advantages of a MG with the presence of a PV, a Wind generation plants and an UPS in terms of critical loads continuity supply are briefly recalled. In section III the proposed MG integrated configuration and the proposed operating logic are illustrated and finally in section IV some numerical experiments in terms of critical loads interruption are presented.

II. PV-WG-UPS INTEGRATED CONFIGURATION

Let us consider a MG consisting of a grid-connected **PV plant** and some **critical loads** grid-connected by an **UPS**.

The system usually appears as reported in the figure below denoted as the Conventional Configuration (CC) (Fig.1).

As well known, the bypass B allows the MS to supply the critical loads in case of failure of the rectifier A and/or of the inverter B.

It's worth to underline that:

a) the PV energy which supplies the critical loads is subject to three conversions (C-A-B);

b) in case of blackout the UPS ensures the critical loads remain in operation for a time depending on the capacity of batteries in storing energy then all the available PV energy could not be used, because the PV plant must be immediately disconnected from grid.

In consequence of point b), the CC does not allow to use the available PV energy just when a blackout occurs; so in this case, the operation of the critical loads can rely only on the batteries autonomy (in general 10 or 20 minutes).

As it well known the PV plant has to be disconnected immediately when a blackout occurs that is when the main supply fails.

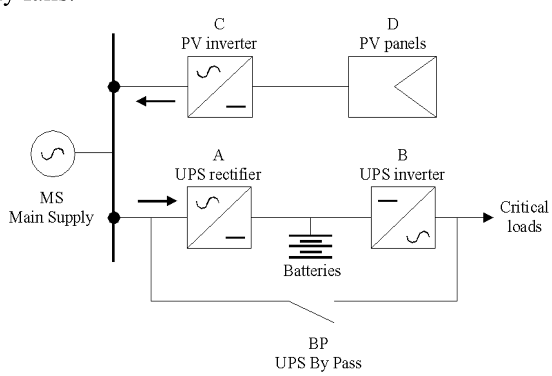

Figure 1. The Conventional Configuration (CC).

In order to use all the available energy sources as much as possible, the exploitation of the PV energy, especially when a blackout occurs, is mandatory. Then, at this scope the Interconnected Configuration named IC1 (see Fig. 2) has been proposed by the authors in a previous paper [7], in which the PV plant is connected by the MPPT converter to the DC bus.

This configuration completely overcomes both the points a) and b) previously mentioned, indeed:

- the PV energy used by the critical loads is subjected to only one conversion (B) instead of three;
- in the case of MS blackout, the PV energy is available like one stored in the batteries.

It is worth to underline that in this case the storage function is performed directly by the batteries of UPS and so no other storage system is necessary as it could be in the case of CC.

It is evident that if a failure occurs during the day when the sun provides enough power so as to completely satisfy the energy demand of the critical loads, the PV plant is sufficient to guarantee the supply of critical loads. On the contrary if the failure occurs at the beginning of the day, just after the dawn, or just to the sunset, the PV energy available could be only sufficient to delay the start of the interruption.

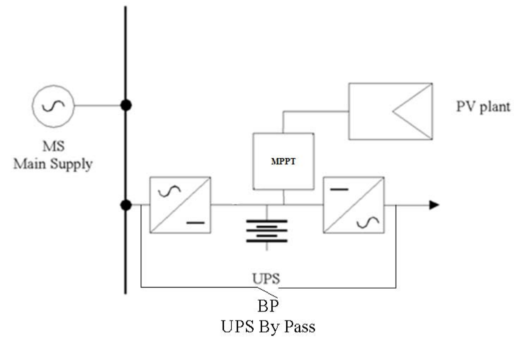

Figure 2. The Interconnected Configuration IC1.

Considering that several design scenarios have been proposed to design integrated renewable energy systems and in order to reduce the critical loads interruptions, the authors have proposed the integrated configuration of Fig. 3, named in the following IC2, in which the presence of a mini WG plant is considered too [8].

The WG plant is connected by the ac to dc converter to the DC bus. In this way the WG available energy is directly supplied to the critical loads or to the grid depending of the energy demand of the local critical loads.

From the simulation results, it has been demonstrated that by the proposed hybrid configuration IC2 some critical network congestions have been faced in a more efficient manner with respect to the configuration IC1 virtually increasing the autonomy of storage system.

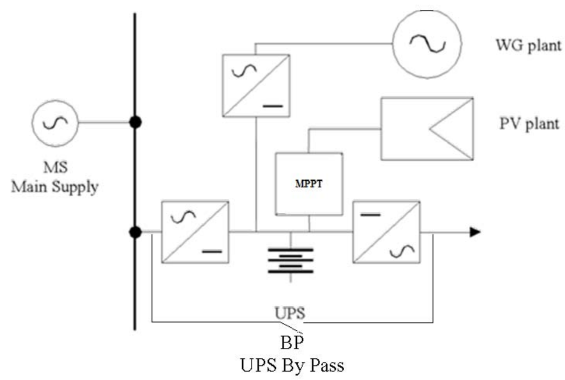

Figure 3. The Interconnected Configuration IC2.

III. THE PROPOSED HYBRID PV-WG CONFIGURATION WITH MORE STORAGE DEVICES

In a hybrid system like that IC2 both photovoltaic and wind energy can be made available as a reserve, this will give added value to energy production that makes higher the value of the same kWh.

There are three arguments in favor of the introduction of a storage system coupled to each renewable source microplant

[9]. First, storage can improve the security of supply. One of the problems concerning the grid quality in Europe is the incidents which can cause a perturbation in the supply of energy to the users. Even in the best grids, such events can occur, and in most of the European countries, the short or long interruptions are quite common. Second, the addition of a storage function can also increase the global performance ratio of a renewable energy generator either by hindering over-voltage disconnection or by storing the energy produced during the disconnection time and feeding it in the grid after reconnection.

Finally, a large penetration of renewable energy, such photovoltaic and wind ones, will not be able to cover all consumption peaks. Therefore, storage seems necessary to defer the energy injection to the grid during the peaks of load which do not correspond to the peaks of renewable energy generation.

Moreover, for the IC2 configuration it is essential to proper sizing and an appropriate management of various system components in order to obtain benefits in economic terms and in terms of reliability of the load supply.

Depending on the required performance system it is possible:

- to conceive a design where the peak wind power and photovoltaics are able together to meet the entire demand for power load (in this case the absorption by the public network would be linked only to the randomness of the sources themselves);
- in presence of MS failure, wind and solar radiation, the operating system would be limited only to the time of discharge of UPS batteries. At this point it is necessary to decide whether, at the approach of the end of battery discharge, it is more convenient to perform selective curtailment of some loads in order to continue to supply the most vital for further time, or keep all loads connected;
- an intermediate size, leading to the decrease of energy network and to increase the time for back-up.

From the above considerations and underlining that in IC2 the two generators, wind and solar, could not contribute to the recharge of the UPS battery, in the paper it is proposed the configuration IC2 with three independent storage system as illustrated in Fig. 4 (this configuration will be denoted as IC3).

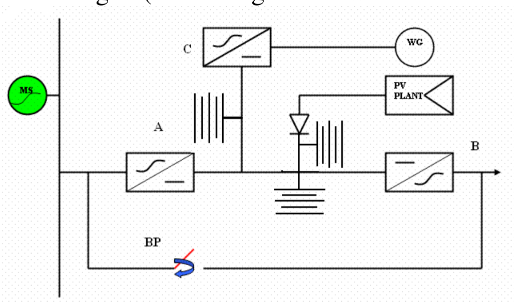

Figure 4. The Interconnected Configuration IC3.

The goal is a better management of energy surplus from wind and from photovoltaics microplants, and to ensure greater reliability of load supply as a result of network failure.
In particular the photovoltaic generator has its own battery rechargeable only by the generator, and the same is for wind generator. Instead, the UPS battery will be subjected to a charge in the following cases:

- the photovoltaic battery is already charged but there is a surplus of photovoltaic energy with respect the load power demand;
- the wind battery is already charged but there is a surplus of wind energy with respect the load power demand;
- in the presence of network when neither the photovoltaic production nor the wind are likely to generate energy surplus.

As regards the operating mode of the three batteries in order to avoid unnecessary waste of energy and the possibility of ending up in a situation with all three batteries discharged or partially charged it has been scheduled an opportune sequence:

- UPS battery;
- PV battery following the complete discharge of UPS battery;
- Wind battery following the complete discharge of UPS battery and PV battery.

Moreover, the PV energy production is consumed before the wind energy production to load supply because of different production costs.

IV. The Reliability Analysis and Numerical Experiments

The reliability is estimated not in terms of the failure rates, but in terms of the number of the critical loads interruptions over a certain period of time; this choice is because the reliability of a system depends on the complexity of the system itself and not only on the number and the failure rates of its components. In order to obtain a deep study of the reliability estimation, several numerical experiments have been carried out by using the well known Monte Carlo simulation method [10]; for sake of brevity, one of the most significant is reported below.

The Mean Time Between Failure (MTBF) and Mean Time Between Repair (MTBR) of the MS and UPS components are reported in Table I; no failure rates are considered for the batteries, the PV plant, the Wind turbine and the interconnections.

The same assumption is taken in regard to the PV plant converter and the Wind plant converter: if they fail the PV and the Wind energy supply the critical loads by means of the interconnection. The power required by the critical loads is assumed uniform and equal to 1 kW. The three batteries are the same and guarantee that the critical loads remain in operation for 10 minutes at most. The PV plant is characterized by a net pick power of 4 kW and, referring to sun irradiation measured in the south of Italy; as assumption, the average output is distributed uniformly on all days of a year so as to give the daily available power shown in Fig. 5.
As well known, the wind resource at a geographic location is highly variable. Power generated from WG plant depends on the wind speed, which fluctuates randomly with time. For this reason the energy output of the wind turbine, characterised by a net pick power of 3 kW, is referred to real data measured in the south of Italy. The numerical experiment covers a period of approximately ten years.

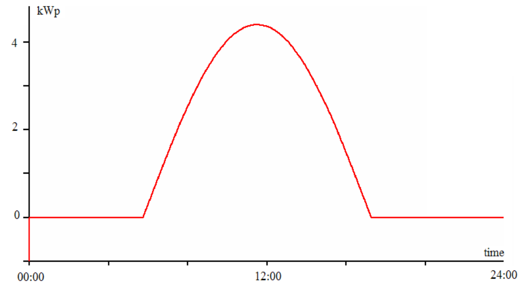

Figure 5. The daily PV available power (all year round).

Along the simulation period, the components of the UPS (i.e. the rectifier, the inverter and the bypass) break several times but never these events implies the interruption of the feeding of the critical loads (it means that each fails of A or B is solved by the bypass closing). Therefore only the fails of the MS are significant in terms of reliability estimation.

TABLE I. MTBF AND MTBR OF MS AND UPS COMPONENTS

Component	*MTBF [hour]*	*MTBR [hour]*
A	170,000	24
B	70,000	24
BP	400,000	24
MS	10,000	1

The numerical results have been reported in terms of charge state of batteries and load supply interruptions considering that each simulation step (0.0001) is equivalent to 30 sec of real time and then to simulate type 1 years we have a Tmax of 106 sec and then to simulate 10 years, we have a total simulation time of about 1000 sec. During the analysed period, the MS is subjected to the fail events illustrated in Table II in terms of the length and when each of them occurs and in Fig. 7.

TABLE II. MS FAIL EVENTS

Event #	Start time	Lenght [min]
1	0:33	1,3
2	19:16	2,7
3	4:31	44,0
4	19:38	45,0
5	19:02	145,0
6	14:47	95,0
7	11:52	165,0
8	20:52	45,0
9	2:56	78,5
10	3:16	45,0
11	14:08	123,0
12	21:02	50,0
13	18:29	19,5
14	22:22	40,0
15	11:27	45,0

In particular, there are only two MS fail events (1 and 2) shorter than 10 minutes, then only in these cases the CC configuration with only the UPS battery assure the load supply. For the other MS events the UPS battery can remain in operation only for 10 minutes, discharging completely and the system does not guarantee supply continuity of critical loads (see Fig. 8).

On the other hand, considering the case of IC2, in presence of PV plant and WG also, because the failures occur during the day when the sun and the wind do not provide enough power so as to completely satisfy the energy demand of the critical loads (see Fig. 9) by means of the interconnection. In this case the autonomy is increased of about 10 minutes (see Fig. 10). In particular, in consequence of the variability of the PV and WG power contributes, they are not sufficient to completely satisfy the load power demand; then the load power difference must be supplied by the UPS battery.

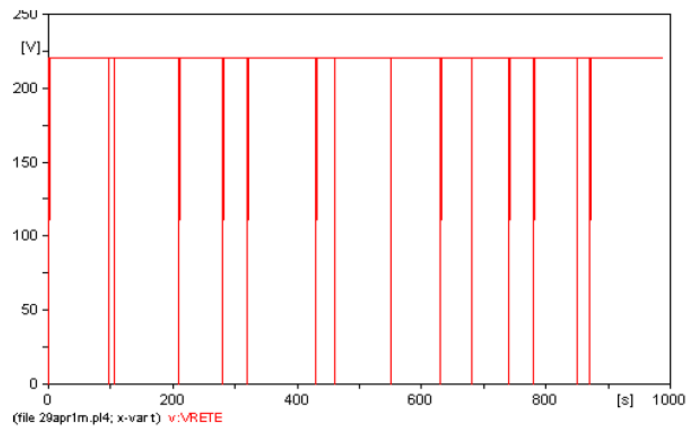

Figure 7. The MS Fail events

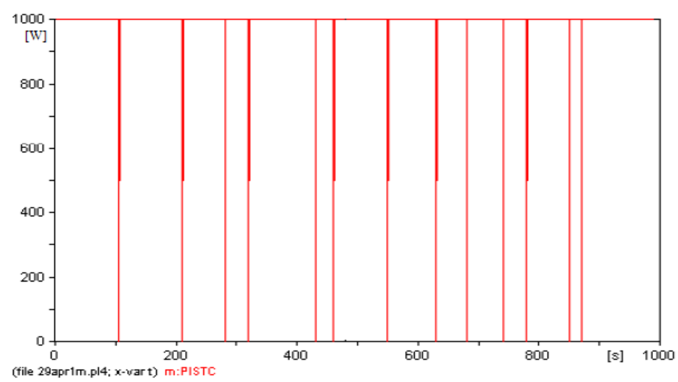

Figure 8. The critical load interruptions considering the set of MS fails events in the case of the CC.

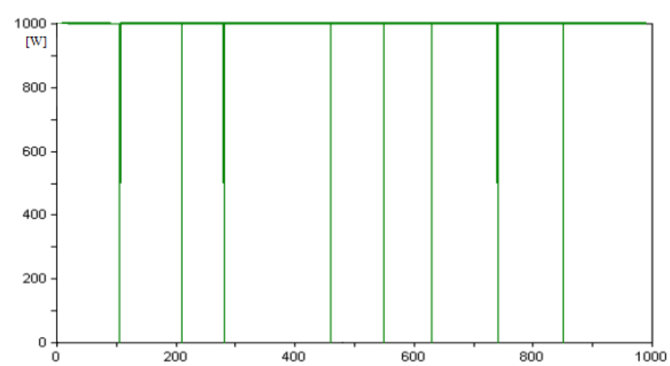

Figure 9. The critical load interruptions considering the set of MS fails events in the case of the IC2.

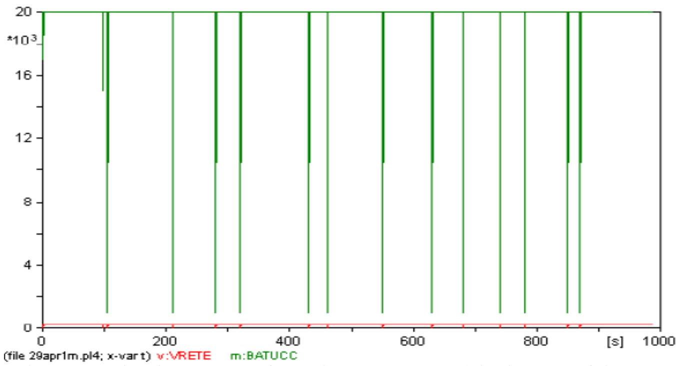

Figure 10. The charge state of UPS battery (BatUCC) in the case of the IC2.

Finally for IC3 thanks to the presence of PV and WG batteries the black-out of load is avoided (see Fig. 11) and as result the autonomy is increased of 20 minutes (see Fig. 12).

It is worth to underline that, in the analysed period, adopting the proposed interconnected configuration IC3 it is guaranteed completely the continuity of load supply in the critical cases of network failures. In particular, the energy not supplied by IC2 is 5.558,3 Wh, while the one givenby IC3 is 3.033,3 Wh.

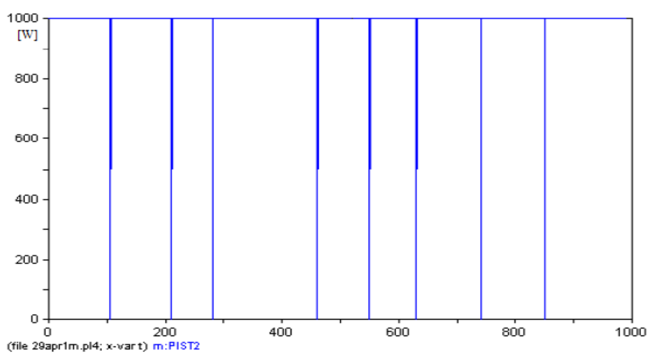

Figure 11. The critical load interruptions considering the set of MS fails events in the case of theIC3.

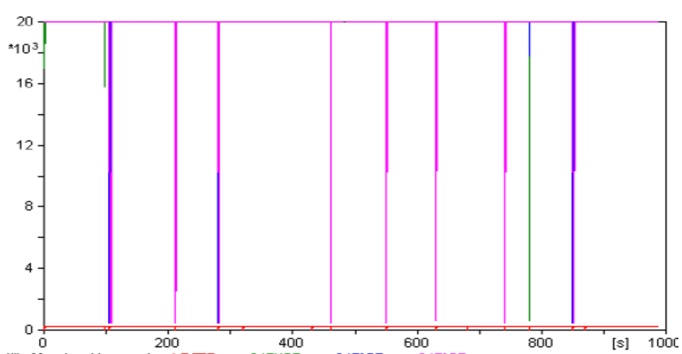

Figure 12. The charge state of UPS battery (BatUFE), the PV battery (Bat2FE) and WG battery (Bat3FE) in the case of the IC3.

V. Conclusions

In this paper, considering the interconnected MG configuration proposed by the authors in previous papers [7-8], the reliability improvements of load supply against network failures taking into account the presence of storage devices for each energy source have been evaluated. From the simulation results, obtained by using the Monte Carlo simulation method, it has been demonstrated that by the proposed hybrid configuration some critical network failures have been faced in a more efficient manner with respect the configuration with only one storage device system..

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