Statistical Analysis of Faults at Off-Grid Inverters for Autonomous PV Systems

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Abstract. In this paper, the maintenance records of a major service center in Greece are presented, regarding inverter faults for autonomous PV systems. A great variety of commercial inverters have been examined, while the fault diagnosis, apparent symptoms and estimated cause of failure are recorded. Analyzing these data, useful conclusions are derived regarding the robustness and common failures of off-grid inverters.

1. Introduction

In autonomous PV systems, the inverter serves as the grid manager, by coordinating photovoltaics and batteries, offering continuous supply to the loads [1]. It is the most critical and sensitive part of the system, usually prone to failures. In order to study common deficiencies and causes of failure, statistical data for a set of 295 failed off-grid inverters are analysed in this paper, derived during a 3-year period at an equipment service center in Greece. The service procedures recorded encompass fault diagnosis, symptoms indicating malfunction and estimated cause of failure for each case, while the analysis undertaken leads to useful findings regarding the weak points of each inverter type and the relation with symptoms and causes of failure.

The study case inverters are classified into five main categories according to the modulation method and other operational characteristics [1]. The *LF pure sine inverters* employ a low frequency transformer and produce sinusoidal voltage with a THD less than 6%. It is the most efficient and reliable type of off-grid inverters with high surge capacity and quite noiseless operation [1]-[3]. On the contrary, a significantly smaller high-frequency transformer is adopted in the *HF pure sine inverters*, leading to more compact equipment, but with surge limitations and lower efficiency [1], [3]. Among the inverter-chargers, the *LF square wave inverter-chargers* have the simpler topology, based on square modulation with no output filter, and are usually used as affordable solutions for heavy load applications [1], [3]. Enhanced voltage waveform is produced by the *LF modified sine wave inverter-chargers*, which utilize transformers with different transformation ratios and may operate on single-phase or three-phase mode [4]. The most sophisticated inverter-charger unit is the *LF pure sine wave inverter-charger*, which is bidirectional, produces almost pure sine output voltage and employs an advanced digital signal processor (DSP) [1].

2. Fault Analysis

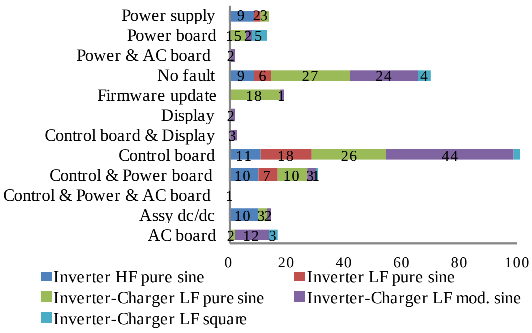

Fig. 1. Fault diagnosis in relation to inverter types.

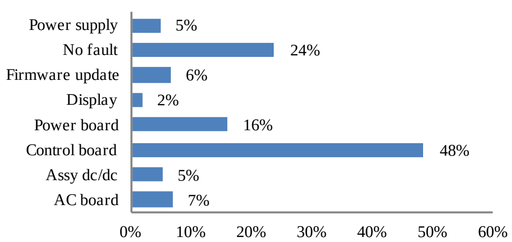

Fig. 2. Incidence of fault diagnosis across all inverters.

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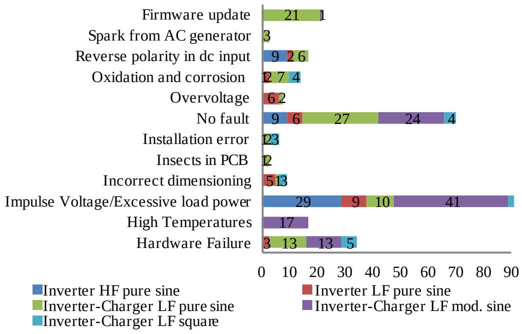

Fig. 3. Causes of fault in relation to inverter types.

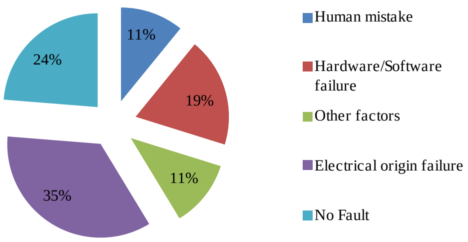

Fig. 4. Causes of fault classified into general categories.

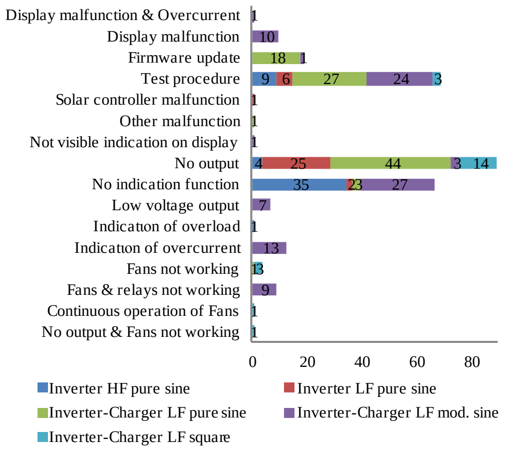

Fig. 5. Failure symptoms in relation to inverter types.

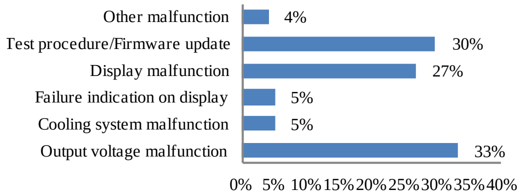

Fig. 6. Incidence of symptoms across all inverter types.

The faults incidence on all 295 failed inverters is depicted in Fig. 1, indicating similar distribution among the five different types. Most common diagnosis is the failure of the control board, which appears as the main fault in 108 cases and as a secondary fault in another 35 cases. This is further confirmed in Fig. 2, in which the incidence rates of each fault type are illustrated. The next most frequently failed part is the power board containing the MOSFETs with a total rate of 16%, while 30% of the examined inverters did not have any actual failure or simply needed firmware update (Fig. 2). Especially for the latter, 18 of the 19 serviced cases were of the LF pure sine inverter-charger type due to the DSP employed (Fig. 1).

In Fig. 3, the estimated cause of failure is depicted for all inverter types. As shown, the impulse voltage and excessive load power are the most common ones, which combined with the overvoltage and spark from generator cases, constitute the major cause of faults: electrical origin failures (35% in Fig. 4). The hardware/software failures appear in one fifth of the cases, only twice incidence compared to the human mistake (incorrect dimensioning, installation error and reverse polarity in the dc input) and the other factors (high temperature, insects on PCB, oxidation and corrosion) categories (Fig. 4).

Regarding the symptoms, it is apparent from Fig. 5 that the most frequent malfunction perceived by the user is related to the output voltage. However, display misoperation (including indication not functioning, no visible indication on display and other malfunctions) appears in a similar high rate (27% in Fig. 6), due to the common failure of the control board. Notably, the display is functional in only 5% of the failed inverters, which highlights the deficiencies of self-diagnosis through the LCD display of the inverter.

3. Conclusion

The analysis above shows that the most vulnerable part, regardless of the inverter type, is the control board, which failed in almost half of the study cases, while the main cause of failure has electrical origin and faults due to human mistake are recorded in more than one tenth of the failures. The most common symptom is no output and display malfunction due to the control unit failure. The LF pure sine inverters prove quite robust, usually damaged by impulse voltages, whereas the HF pure sine inverters frequently fail due to excessive load demand. Poor ventilation and cooling system malfunction, which leads to overheating and system failure, is commonly recorded in LF square wave and modified sine inverter-chargers, while the LF pure sine wave inverters-chargers present software-related failures, readily serviced by firmware update.

References

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