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ARTICLE

Design and Implementation of an Emergency Photovoltaic Power System with Automatic Transfer for a Maquiladora Plant

Diseño e implementación de un sistema fotovoltaico de emergencia con transferencia automática para una planta maquiladora

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Abstract

An unscheduled power outage can interrupt communication and shipment activities in a manufacturing plant, even after production is complete. This study presents the design, installation, and functional evaluation of an emergency photovoltaic power system for selected Information Systems equipment in a maquiladora plant in Matamoros, Tamaulipas, Mexico. Electrical demand was monitored for approximately 48 hours with a Circutor AR6 analyzer and remained between about 100 and 200 W. A constant design load of 200 W and a six-hour backup target required 1.2 kWh of energy. The installed system included two 160 Wp photovoltaic modules, a 20 A charge controller, two 12 V, 110 Ah batteries connected in parallel, a 300 W inverter, and a single-phase automatic transfer switch. Two existing UPS units remained connected between the backup circuit and the selected equipment. During a simulated utility outage, the switch selected the emergency power supply, and both UPS units continued operating for several minutes. The system also returned automatically to the normal power supply. A review of the original calculations identified the need to distinguish nominal equipment ratings from usable backup energy. The observations support functional operation under the tested conditions. The six-hour backup duration and the actual transfer time remain unverified because the original test did not include a complete discharge measurement or an instrumented record of source changes.

During the period the solar photovoltaic plant was installed, we were informed that an unscheduled power outage occurred over a weekend (a non-working day). This allowed for an automatic functional test of the backup power system's connection and disconnection processes. The power outage lasted approximately two hours, and there was no need for the systems engineer to be present at the plant.

Index terms: photovoltaic system, battery storage, emergency power supply, automatic transfer switch, maquiladora industry.

Resumen

Un corte de energía no programado puede interrumpir la comunicación y los embarques de una planta manufacturera, aun cuando los productos ya estén fabricados. Este estudio presenta el diseño, la instalación y la evaluación funcional de un sistema fotovoltaico de emergencia para equipos seleccionados de Sistemas de Información de una maquiladora en Matamoros, Tamaulipas, México. La demanda eléctrica se registró durante aproximadamente 48 horas con un analizador Circutor AR6 y se mantuvo entre 100 y 200 W. Una carga de diseño constante de 200 W y un respaldo previsto de 6 horas dieron como resultado un consumo de 1.2 kWh. El sistema instalado incluyó dos módulos fotovoltaicos de 160 Wp, un controlador de carga de 20 A, dos baterías de 12 V y 110 Ah conectadas en paralelo, un inversor de 300 W y un interruptor de transferencia automática monofásico. Dos UPS existentes permanecieron conectados entre el circuito de respaldo y los equipos seleccionados. Al simular una falla de la red, el interruptor seleccionó el suministro de emergencia y ambos UPS continuaron operando durante varios minutos. También se observó el retorno automático al suministro normal. La revisión de los cálculos permitió distinguir entre las capacidades nominales de los equipos y la energía de respaldo útil. Los resultados muestran el funcionamiento del conjunto en las condiciones probadas. La autonomía de seis horas y el tiempo real de transferencia siguen sin verificarse, pues la prueba original no incluyó una descarga completa ni un registro instrumentado de los cambios en el suministro.

Cabe mencionar que durante el tiempo que estuvo instalada la planta solar fotovoltaica, nos reportaron que un fin de semana (día no laborable) se presentó un corte de energía eléctrica no programada, permitiendo hacer una prueba funcional automática de conexión y desconexión del sistema de energía de respaldo en forma automática. El corte de energía duró aproximadamente 2 horas y no hubo necesidad de que el ingeniero de sistemas tuviera que presentarse en la planta.

Palabras clave: transmission lines, ABCD parameters, nominal π model, active power losses, error analysis.

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I. INTRODUCTION

Manufacturing plants need electrical power for more than running production machinery. Communication, data processing, and shipment activities also depend on it. In addition, power disturbances can affect manufacturing beyond the plant where they occur by interrupting supply-chain activities [1]. At the maquiladora plant considered in this study, the Information Systems department maintained communication among the different areas of the plant and with customers. An unscheduled power outage could therefore interrupt information flow and delay product shipments, even when products had already been manufactured. For this reason, the project focused on supplying backup power to a small group of critical loads instead of supporting the entire plant.

Photovoltaic generation is generally associated with energy production during daylight hours. However, when combined with battery storage and an inverter, it can also provide emergency power. Previous studies have presented PV–battery systems capable of operating while connected to the utility and of supplying loads in islanded operation during an outage [2]. Grid-interactive uninterruptible power supply systems that combine photovoltaic generation, batteries, and an auxiliary generator have also been implemented [3]. More recently, field studies have brought together critical-load measurement, component sizing, automatic transfer, and backup testing in the same PV–battery application [4]. Although these systems differ in capacity and configuration from the one presented here, they show the role of battery storage when photovoltaic energy is intended for backup and not only for energy savings. Studies in commercial facilities also suggest evaluating PV and battery systems by considering continuity of service alongside financial performance [5].

In this paper, the term emergency photovoltaic power system refers specifically to the photovoltaic modules, battery bank, charge controller, and inverter used as the emergency power supply. The utility remains the normal power supply, and an automatic transfer switch selects between the two sources. This arrangement differs from a conventional grid-connected photovoltaic plant because the photovoltaic source is designed to supply only selected Information Systems equipment during an outage.

Backup system design begins with the load that must remain in operation. The required photovoltaic capacity and battery storage depend on the load profile, the expected duration and timing of the interruption, the available solar resource, conversion losses, and the operating limits of the batteries [6], [7], [8]. Although several studies approach this task as an optimization problem, the present project followed a simpler procedure based on direct measurements. The consumption of the selected Information Systems equipment was recorded for approximately 48 hours and remained between about 100 and 200 W. These measurements, along with a desired backup period of six hours, formed the basis for selecting the photovoltaic modules, battery bank, charge controller, and inverter.

Having energy stored in the batteries is only part of the solution. The system must also detect the loss of the normal power supply, connect the emergency power supply, and return the load to the utility when service is restored. When selecting a transfer switch, consider the arrangement of both sources, as well as the grounding and neutral configuration [9]. In addition, photovoltaic systems with battery storage require safety considerations during design, installation, and operation [10]. For the prototype presented in this study, a single-phase automatic transfer switch was built to perform the change between the normal and emergency power supplies. The backup circuit included only the selected Information Systems equipment, connected through two UPS units.

Within the literature reviewed for this work, most studies address residential or commercial applications, grid-interactive systems, or larger microgrids. For the design of the emergency solar photovoltaic plant, in addition to consulting various authors, the research focused on the mexican standard NOM-001-SEDE-2012, specifically article 690 “solar photovoltaic system”, and, in particular, article 690-10 “Off-Grid systems”. Fewer published case studies

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describe the design and functional testing of a small PV–battery backup system intended specifically for Information Systems equipment in a Mexican border maquiladora. The case studied here also differs from projects intended to supply production motors or the entire industrial installation. Its purpose was narrower: to support a load with relatively low power demand but an important role in the plant's operation and shipment activities.

Therefore, this work aimed to design, implement, and evaluate an emergency photovoltaic power system with automatic transfer for the Information Systems equipment of a maquiladora plant in Matamoros, Tamaulipas, Mexico. The study covers identifying and measuring the critical load, sizing components, installing the system, and functionally testing the transfer arrangement. It also re-examines the agreement between the measured demand, the selected equipment, and the behavior reported during the original project. The six-hour backup period is treated as a design target because the functional test did not include a complete autonomy measurement. For the same reason, we present the results as evidence of functional transfer and short-term operation rather than proof of uninterrupted transfer or long-term reliability.

II. Materials and Methods

This case study is based on the installation carried out in 2018 and documented in the original master's thesis [11]. We reviewed the recorded power plot, component specifications, sizing calculations, installation photographs, and the functional test description. The analysis follows the original project from load measurement to operation of the emergency power supply.

The methodology for the design of the solar photovoltaic plant was derived from several research articles, but primarily from Article 690-10 “Off-Grid Systems”, which cover inverters, electrical protections, electrical conductors, and energy storage methods (batteries).

A. Site and selected equipment

The project was carried out at an automotive maquiladora plant in Matamoros, Tamaulipas, Mexico. The selected Information Systems equipment supported communication within the plant and with customers. The backup circuit served this equipment group through two existing UPS units. Production machinery was outside the installation scope.

The guardhouse at the plant entrance, along with maintenance personnel, was selected as the location for the photovoltaic modules, battery bank, charge controller, and inverter. The automatic transfer switch was installed near the Information Systems equipment. The utility supplied the backup circuit during normal operation, while the inverter provided the emergency power supply during an outage.

B. Electrical demand and backup period

A Circutor AR6 power analyzer was installed at the electrical panel supplying the selected equipment. Monitoring covered approximately 48 continuous hours, from 11 to 13 April 2018. The resulting power plot was used to identify the demand range and select a design load of 200 W.

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The original project adopted a six-hour backup period based on the local outage history described in the thesis. This duration served as the design condition. The available record does not include a statistical distribution of outage duration, so it cannot establish what proportion of local interruptions would be covered.

C. Component sizing

The energy required at the backup circuit was calculated for a constant load as:

$$E_{\text{load}} = P_{\text{design}} \times t_{\text{backup}} \tag{1}$$

where E_{load} is the energy requirement in Wh, P_{design} is the design load in W, and t_{backup} is the desired backup duration in hours.

The original sizing procedure added 30% to this energy requirement to account for system losses. The same allowance was retained here when reconstructing the original calculations. Photovoltaic capacity was then estimated using

$$P_{\text{PV,calc}} = \frac{1.30\, E_{\text{load}}}{H_{\text{PSH}}} \tag{2}$$

where $P_{\text{PV,calc}}$ is the calculated photovoltaic capacity, and H_{PSH} is the equivalent number of peak sun hours for the reference day. The project used an annual-average value of 5.12 peak sun hours per day and a design tilt of 22.7°. These were reported design inputs; the project did not include an on-site solar resource record.

The calculation estimates array capacity on an energy basis and does not establish the recharge time under a particular day's weather.

Battery capacity was calculated using the nominal bank voltage:

$$C_{\text{calc}} = \frac{1.30\, E_{\text{load}}}{V_{\text{bank}}} \tag{3}$$

where C_{calc} is the calculated capacity in Ah and V_{bank} is the nominal battery-bank voltage in V. The original procedure did not specify a separate allowable depth of discharge or measured conversion efficiency. We therefore examined these assumptions when interpreting the selected battery capacity.

The charge controller was selected using the combined module current for a parallel connection. The inverter was selected by comparing its continuous power rating with the recorded load. A pure sine wave unit was chosen because the backup circuit supplied electronic equipment.

D. Equipment and installation

Table 1 summarizes the installed equipment. The two photovoltaic modules were connected in parallel. The two batteries were also connected in parallel, maintaining a nominal bank voltage of 12 V.

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TABLE 1
INSTALLED COMPONENTS OF THE EMERGENCY PHOTOVOLTAIC POWER SYSTEM

Component	Model or arrangement	Nominal rating or function
PV modules	Two Luxen LNSA-160P modules in parallel	160 Wp each; 320 Wp total
Charge controller	EPSOLAR LS2024B, PWM	20 A
Battery bank	Two LTH deep-cycle batteries in parallel	12 V, 110 Ah each at C20; bank: 12 V, 220 Ah
Inverter	EPCOM EPI-300-12, pure sine wave	12 V DC input; 300 W continuous
Transfer switch	Custom relay arrangement	Single-phase, 120 V, 60 Hz; automatic source selection
UPS units	Two existing units downstream of the transfer switch	Supply the selected Information Systems equipment

Source: equipment specifications and installation records in the original thesis [11]. C20 denotes capacity rated over a 20-hour discharge period.

The photovoltaic modules were placed on the guardhouse roof. The charge controller and electrical protection devices were installed in an outdoor enclosure under the roof overhang. The battery boxes were mounted on supports outside the guardhouse, with natural ventilation. These components were located on the east side of the building. The inverter was installed indoors, in the air-conditioned guardhouse. Fig. 1 shows the installation documented in the original project.

The automatic transfer switch used two main relays, a control relay, an on-delay relay, and green and red indicator lamps. It was built for single-phase operation at 120 V and 60 Hz. The utility was connected as the normal power supply and the inverter as the emergency power supply. The on-delay relay was set to about three seconds to return to the utility. Both UPS units remained downstream of the transfer switch.

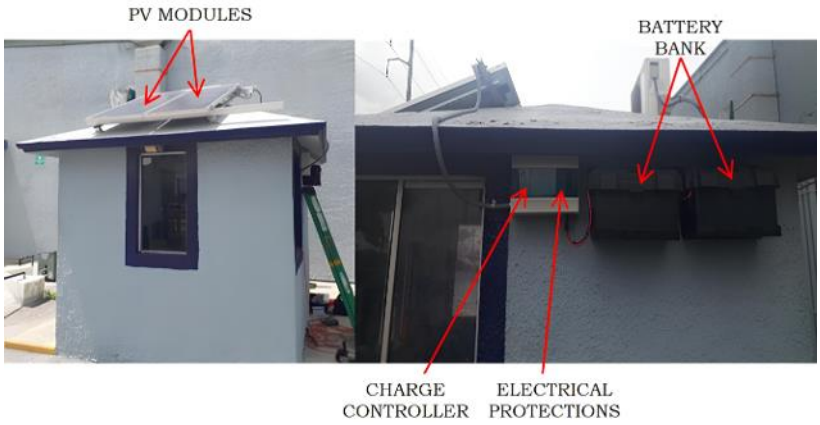


Fig. 1. Emergency photovoltaic power system installed at the guardhouse. The photographs show the rooftop modules and the outdoor battery boxes, charge controller, and electrical protection devices. Original Spanish annotations are retained. Reproduced from the original thesis, Fig. 9.12 [11].

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E. Functional test and technical review

The functional test performed was as follows:

1. The electrical power supply to the battery-backed power units (UPS) was disconnected.
2. On the transfer switch, the green light (normal supply) turned off, and the red light (emergency supply) turned on. It was verified that the UPS units continued to operate normally.
3. The backup power system (batteries) was left running for 2 hours.
4. After the test period, the normal electrical power supply was reconnected. At this point, the red light on the transfer switch (emergency supply) turned off, and the green light (normal supply) turned on.

This test confirmed that the system is ready to function correctly during an unplanned power outage and to return to its initial state once the normal electrical power supply is restored.

The available description covers a short functional test; it does not include a complete battery discharge or a waveform recording of the change between sources.

For the technical review, we compared the original calculations with the installed nameplate ratings. We also separated the initial voltage check, the UPS alarm duration, and the return delay, since these observations describe different parts of the test.

III. Results

A. Electrical demand and backup energy sizing

The power trace obtained with the Circutor AR6 (see Fig. 2) showed a demand of approximately 100–200 W during the monitoring period. In the available plot, the load stayed close to 100 W for much of the record, with occasional values near 200 W. We used the upper value to size the emergency photovoltaic power system.

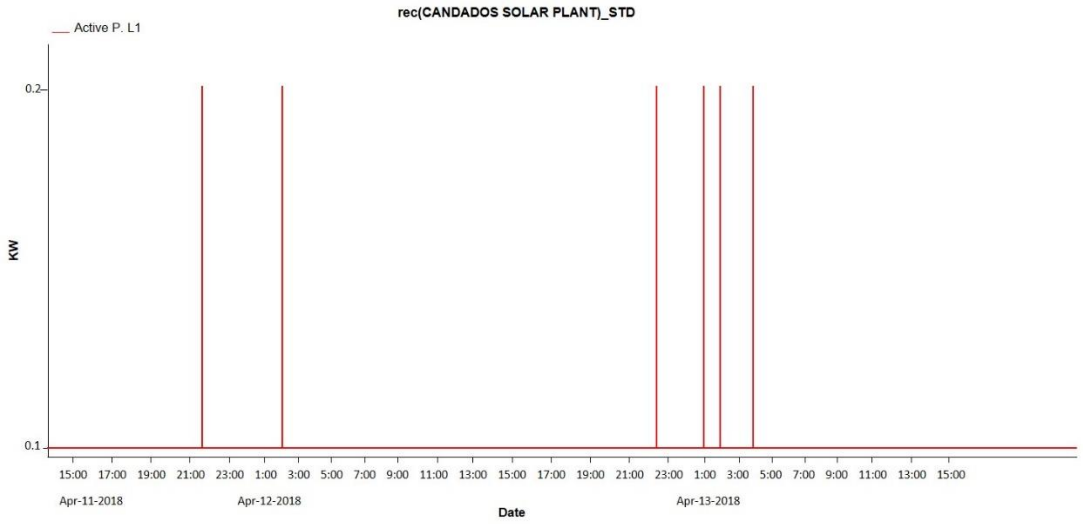


Fig. 2. Electrical demand recorded with the Circutor AR6, 11–13 April 2018. The vertical axis is in kW: 0.1 and 0.2 kW correspond to 100 and 200 W. Reproduced from the original thesis, Fig. 9.2 [11].

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A continuous load of 200 W over six hours, as indicated in Eq. (1), required 1,200 Wh of energy. Incorporating the 30% allowance from the original method increases this value to 1,560 Wh. These figures represent the calculated energy required for the backup period and are not derived from a six-hour discharge test or from summing recorded power consumption.

B. Calculated and installed capacities

With 1,560 Wh and 5.12 peak sun hours, Eq. (2) gave a photovoltaic capacity of 304.7 Wp. Two 160 Wp modules provided a combined nominal capacity of 320 Wp, approximately 5% above this calculated value. Table 2 compares the original selection basis with the installed equipment.

TABLE 2
COMPARISON OF THE SELECTION BASIS AND INSTALLED EQUIPMENT

Component	Basis used in the original procedure	Installed value
PV array	304.7 Wp calculated from 1,560 Wh and 5.12 peak sun hours	320 Wp
Charge controller	17.5 A combined module current at maximum power	20 A
Battery bank	130 Ah calculated at 12 V	220 Ah at 12 V, rated at C20
Inverter	200 W design load	300 W continuous

Calculated values reproduce the original selection procedure with consistent units and rounding. They do not represent measured usable capacities.

Each module had a maximum-power current of 8.75 A, giving 17.5 A for the parallel pair. This was the current used in the original controller selection. The module data also listed a short-circuit current of 9.21 A, or 18.42 A for the pair. These two current values describe different operating conditions and should not be treated as interchangeable.

Equation (3) gave a battery capacity of 130 Ah. The two installed batteries provided a nominal combined capacity of 220 Ah at 12 V, equivalent to 2.64 kWh. Each battery's 110 Ah rating corresponded to a 20-hour discharge rate, commonly expressed as C20. The nominal energy therefore does not represent a measured amount of energy available at the AC backup circuit.

The recorded demand range was about 33–67% of the inverter's 300 W continuous rating. This comparison uses the earlier load record; inverter loading during source changes and UPS recharging was not recorded separately.

C. Operation during the functional test

The initial check gave an inverter output of 120 V AC. With the utility connected, both UPS units were connected to the backup circuit and their displays indicated normal operation.

When the normal power supply was disconnected, the green indicator turned off, and the red indicator turned on. Both UPS units produced supply-failure alarms that cleared after approximately ten seconds. They continued operating on

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the emergency arrangement for several minutes, and the original test description reported no operating problem during that observation period.

When the utility was restored, the red indicator turned off, and the green indicator came on approximately three seconds later. This observation was consistent with the on-delay relay setting used for the return to normal supply. Neither the ten-second alarm period nor the three-second return delay measures the initial transfer time during the simulated outage.

IV. Discussion

A. Backup power for selected Information Systems equipment

The relatively small electrical demand allowed the project to focus on the communication equipment used in plant and shipment activities. In this case, the practical task was to connect a small photovoltaic emergency power supply to an existing circuit with two UPS units.

The installation also used space already available at the guardhouse. This arrangement shows how the components were placed within an operating industrial site. The test supports the feasibility of the assembled arrangement under the observed conditions, although the effect on shipment delays or other plant activities was not measured.

B. Interpretation of the sizing calculations

The load measurements provided a practical starting point for the design. Using 200 Was a constant load was a cautious choice relative to the available trace, which remained near 100 W for much of the monitoring period. Jivaganont et al. [12] emphasize the role of load characteristics and their variation when selecting photovoltaic and battery capacities. Their work supports examining the actual demand before choosing equipment, although it does not validate the particular load or backup period used here.

A maximum taken from a short record can still miss other operating conditions. Louie and Dauenhauer [13] found that load-estimation errors affect the cost and reliability of small off-grid photovoltaic systems. They also showed that an accurate estimate of average energy demand alone may be insufficient when the timing of consumption is poorly represented. In this case, 200 W is a design value supported by about 48 hours of observation. A longer record would be needed to assess whether it also covers changes in equipment use or demand over other periods.

At a constant load of 200 W, six hours of operation require 1.2 kWh at the AC backup circuit, before accounting for conversion losses and usable battery capacity. Khoury et al. [8] considered demand, weather, outage conditions, and battery operating constraints when sizing a residential photovoltaic backup system. This supports treating load and backup duration together. The six-hour choice in the present study came from the local outage history described in the original project; the cited literature does not establish six hours as a general requirement.

A defined backup period also differs from a quantified reliability level. Tan et al. [14] used load, weather, and outage information in a stochastic battery-sizing method. Such an approach can examine different interruption conditions. The present calculation addresses one selected load and duration, so it does not provide a probability of maintaining supply or demonstrate six hours of actual operation.

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The treatment of losses deserves particular attention. Adding 30% to the load energy gives 1,560 Wh. If losses instead represented 30% of the input energy, the calculation would be 1,200/0.70, giving approximately 1,714 Wh. With the same solar input, this would correspond to 334.8 Wp, above the installed 320 Wp. This comparison illustrates the effect of how the allowance is defined; it is not a measurement of the system's losses. A more detailed assessment would use the operating efficiencies of the installed components.

The same distinction matters for the battery bank. Its nominal energy of 2.64 kWh exceeds the 1.2 kWh required at the AC circuit, but this comparison alone does not establish the backup duration. The usable energy depends on the initial state of charge, allowable discharge, battery condition, and conversion losses. The C20 rating also applies to a specified discharge current. The battery current during backup operation was not recorded, so we could not establish the capacity available under those conditions. Battery operating constraints should therefore be considered explicitly, as in the sizing approach discussed by Khoury et al. [8].

Controller selection also requires closer attention. The 17.5 A used in the original procedure was the combined current at maximum power. The combined short-circuit current was 18.42 A, close to the controller's 20 A rating. Comparing these figures is useful, but it does not by itself confirm the available design margin. That assessment requires the manufacturer's input limits and the relevant electrical design criteria.

C. Automatic transfer and the role of the UPS units

Both UPS units continued operating during the simulated outage, and the switch returned the circuit to the utility when service was restored. These observations describe the combined system's behavior. The UPS units were already part of the installation and could bridge a brief interruption while the source changed. Continued UPS operation therefore cannot be used to claim that the automatic transfer switch itself provided uninterrupted power.

The UPS alarm duration and the programmed return delay describe different events. A direct voltage recording at the transfer-switch output would be needed to measure the interruption during the initial source change. Ransom [9] discusses how transfer-switch selection depends on the supply arrangement and grounding and neutral configuration. These design considerations remain relevant even when a short operational test is successful.

The installation included electrical protection devices and protected component locations. However, the functional test did not evaluate fault interruption, protective-device coordination, or battery hazards. Cabrera-Tobar et al. [10] address safety considerations across the design, installation, and operation of photovoltaic and battery systems. Their framework helps identify aspects for a fuller technical assessment of this prototype; it does not establish compliance of the installation described here.

D. Contribution and limits of the case study

The main contribution is the documented sequence from a measured industrial load to equipment selection, installation, and a functional test with existing UPS units. Other photovoltaic applications have reported more extensive backup testing, including the case presented by De la Torre-Guzmán et al. [4]. The capacities and test conditions differ, so those results cannot be transferred directly to this installation.

For this case, a complete backup test would be needed to relate energy delivered at the AC circuit to the six-hour target. Recording photovoltaic output and battery behavior during the test would help distinguish solar contribution from battery-supplied energy. Measurements during the source changes would address the transfer-time question, while a recharge record would show how the system recovers after an outage.

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The financial effect also remains outside the measured results. Badiei and Campos do Prado [5] show why continuity of service and financial performance need to be considered together when assessing photovoltaic and storage systems. The original project did not provide the cost and operating records needed to quantify savings, avoided shipment losses, or a payback period.

V. CONCLUSIONS

An emergency photovoltaic power system was designed and installed for selected Information Systems equipment in a maquiladora plant in Matamoros, Tamaulipas, Mexico. The recorded demand of approximately 100–200 W provided the basis for selecting a 320 Wp photovoltaic array, a nominal 12 V, 220 Ah battery bank, and a 300 W inverter.

During the simulated utility outage, the automatic transfer switch selected the emergency power supply, and both UPS units continued operating during the observation period. The system also returned automatically to the normal power supply when it was restored. These observations demonstrated the combined arrangement's functional operation under the tested conditions.

The technical review helped distinguish the calculated energy requirement from the installed nominal capacities. Supplying a constant load of 200 W for six hours requires 1.2 kWh at the AC backup circuit. Although the installed capacities exceeded the values obtained with the original sizing procedure, the available records do not demonstrate that the system delivered this energy. Battery discharge limits, conversion losses, and solar availability remain important when assessing the achievable backup duration.

During the year that the emergency solar photovoltaic plant was in operation, an unscheduled power outage occurred on a Saturday (a non-working day) and lasted approximately 2 hours. Throughout this time, the information system continued to function properly, without the need for the systems engineer to return to the plant to shut down the system, wait, or come back once power was restored to bring the system back online.

The case provides a practical reference for integrating photovoltaic backup with existing UPS equipment in a small industrial application. Its main contribution is the documented process from load measurement to installation and functional testing. A complete backup test and instrumented measurements during source changes would be needed to verify the six-hour target and determine the actual transfer time.

CRediT (*Contributor Roles Taxonomy*)
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