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Renewable energy integration for smart sites

Asim Kaygusuz [a,*], Cemal Keles [a], Baris Baykant Alagoz [a], Abdulkerim Karabiber [b]

[a] Inonu University, Engineering Faculty, Electrical-Electronics Engineering, Turkey
[b] Bingol University, Engineering Faculty, Electrical-Electronics Engineering, Turkey

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ABSTRACT

Use of distributed renewable energy sources for domestic energy consumption will increase in the near future, due to its advantages as being clean and infinite energy generation possibility. This trend allows more efficient energy consumption because of reducing transmission loses and dependence of domestic appliances to grid distribution. This study investigates potentials of a smart site concept based on domestic renewable energy generation. The study addresses site scale integration of hybrid renewable sources and grid energies as well as investigates possible advantages of the use of hybrid renewable energy systems based on solar and wind power. A continuous energy mixing strategy is used for DC integration of hybrid renewable energy (wind + solar) and the grid energy to meet site power demand. The proposed case study demonstrates that the smart site with hybrid renewable sources considerably reduces energy dependence of the house appliances to the grid which in turn presents a feasible solution for implementation of distributed generation provision for future smart grids.

1. Introduction

The latest trend in domestic energy management of a smart grid paradigm includes distributed renewable generation, distributed energy storage possibilities, demand-side load management. The complexity of the electric power infrastructure continues to grow with increasing load demand [1]. In order to respond to this in an environment friendly manner, the integration of distributed renewable energy farms and the utilization of distributed energy storages are becoming major concerns for stakeholders involved in the design of future energy delivery grids [2]. Adoption of renewable multi-generation systems for local and decentralized electricity generation can lead to significant benefits in terms of higher energy efficiency, reduced CO_2 emissions and enhanced economy [3].

Today fossil fuels continue supplying much of the energy used worldwide, however renewable energy is the world's fastest growing energy market due to advances in renewable energy systems [4]. Renewable energy served with improved control devices and techniques has the potential for infinite use. The integration of existing grids with renewable sources provides economical, sustainable and efficient power distribution, and this allows the control of the greenhouse effect. Sharing renewable energy of distributed generators in the site scale can considerably reduce energy demands from the grid, and thus, more environment-friendly energy harvesting and efficient energy distribution will be possible in the near future. Utilization of one or more renewable sources for hybrid power systems (HPS), such as a combination of wind turbines and solar panels will support local energy demands more efficiently than solo renewable energy installations because of hourly changing regional wheatear and irradiation conditions [5].

Energy generation based on photovoltaic and wind energy is recognized as cost-effective way for improving social life standards in remote rural areas as isolated power system [6]. However, there is extensive interest for the integration of distributed renewable sources in future smart grid structures for sustainable and affordable energy generation. Domestic level [7–11] and grid level renewable energy integration and management methods had been addressed in many recent works [12–17].

The impact of residential building-integrated photovoltaics on the energy demand of multi-family dwellings was analyzed for the potential of seven building integrated Photovoltaics technologies implemented in a residential prototype simulated in three different cities in Brazil [18]. The study demonstrated that there is a considerable amount of energy to be harvested from vertical facades [18]. Mithraratne considered microgeneration of electricity in urban houses in New Zealand at the single-building-scale using gridconnected roof-top wind turbines [19].

This study investigates advantages of hybrid renewable energy (solar + wind) utilization in a smart site concept that composed of several residences and site services. A DC integration method was used for continuously mixing grid energy and renewable energy

* Corresponding author. Tel.: +90 5363672021; fax: +90 4223410046.
E-mail addresses: asim.kaygusuz@inonu.edu.tr, akaygusuz@gmail.com (A. Kaygusuz).

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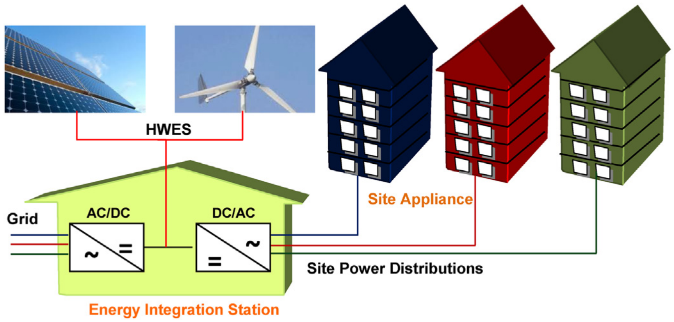

Fig. 1. Smart site concept with HWES integration.

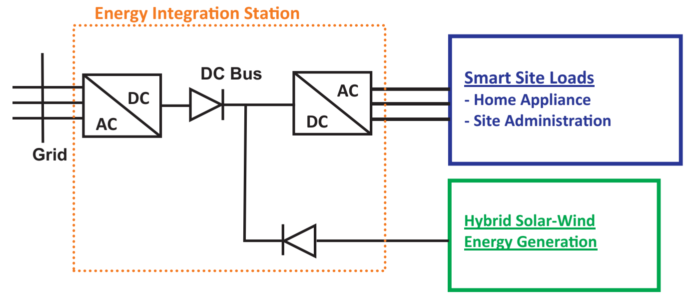

Fig. 2. Electrical schema of energy integration station using the continuous DC energy mixing method.

generated by solar panels and wind turbines in site power management simulations. Author presents a case study and demonstrates that the site level integration of renewable sources can considerably reduce the dependency to the grid energy and enhance the power quality and reliability for the site appliance.

The paper is organized as follows: smart site concept and in-site renewable energy integration method are introduced in the following section. The next section is devoted to demonstrate smart site simulation results of a typical case study.

2. Smart site using renewable energy sources

Mixing of energy generated from various sources is one of main concerns for the small scale distributed renewable source integration in the domestic level. Due to intermittent and uncertain character of the wind and solar generation, renewable energy generation requires a backup energy source to preserve power quality and energy balance between generation and consumption. Today, domestic use of hybrid wind and solar energy system (HWES) should be considered as a supportive energy source to reduce dependence of domestic appliance to the grid energy. However, high installation, management and maintenance costs of the HWES make them difficult to apply at home. This is the main complication reducing rate of the domestic level implementation of renewable energy systems.

Nowadays increasing demand for personnel security and time efficiency in the social life, residences turns into smart sites. Smart site provides self-supportive living environments including security serves, telecommunication network, sport and entertainment facilities and shopping opportunities in the site territory. The HWES integration in the smart site reduces dependence of site energy demand to local power distribution grid and makes smart sites self-supportive in term of energy requirement. HWES also provide clean and sustainable energy for the domestic consumption and hence environment-friendly green buildings can be possible by the smart site with HWES integration.

Microgrids are the smallest fragments of future smart grid [2,14,15,20,21]. Smart sites with HWES can be an efficient solution for implementation distributed generation in microgrids. Local generation and consumption so called the distributed generation improves energy efficiency because of reducing transport losses and energy demand from the grid [1,2,22–24].

Site level implementation of the HWES will be much feasible comparing to the stand alone home installation. This is because of that larger scale installation and maintenance of HWES are more affordable comparing to the per house installation. Fig. 1 describes hybrid energy use in the smart sites. The energy integration station is used to support the renewable energy generation with the grid energy. The whole site power demand is supplied by three phase output of the energy integration station. Each phase line feeds a house group or an apartment including site administration appliances. Fig. 2 shows the electrical schema of the energy integration station performing continuous DC energy mixing from the DC bus [13–15]. The system composed of an AC/DC converter, a DC/AC converter and diodes. The AC/DC converter generates 580 V DC voltage on the DC bus. Diodes in the station indicate the directions of current flows, and correspondingly energy flows. The voltage from solar and wind sources rise to 600 V DC and connected to DC bus via D2 diode. The three phase DC/AC converter converts 600 V DC voltage to 220 V three phase AC voltage and supplies the site appliance and homes. The system is configured as that 600 V DC is primarily derived from hybrid renewable sources as long as the hybrid renewable sources supply a DC voltage greater than the voltage coming from grid, which is 580 V. In this way the system is considered to use much energy from the renewable sources. When the power of renewable sources is not enough for the site consumption, it results in the decrease of DC voltage on DC bus and the grid contributes the renewable energy to supply the demanded energy by site. This allows a continuous mixing of energies coming from renewable sources and the grid depending on power status of renewable sources. DC continuous energy mixing provides a satisfactory AC voltage stability under intermittent and fluctuating power generation of renewable sources [11,15]. Voltage synthesis from DC bus by DC/AC converter isolates the voltage signal from the grid and it is advantageous for filtering the noise in grid voltage.

3. Case study

In this section, case studies are conducted for investigating advantages of the HWES integration in a medium-size smart site concept. The smart site consists of 15 homes and a site administration. Hourly hybrid wind and solar generation data derived from the Capo Vado site reports [9] are used for the modeling of hybrid renewable source generation potential in the site simulation. The considered site is in Liguria, Italy, has high potential of wind energy. Dynamic site loads representing regular home user and site administration appliances were used for electrical energy consumption in modeling the smart site. These appliances are switched on or off according to hourly consumption profiles of the homes considering household activities. This schedule is given in Table 1. Fig. 3(a) illustrates the home appliances used for the modeling regular home consumption. Fig. 3(b) illustrates the electrical loads representing a site administration office and site serves. Site administration consumption profiles are also generated for hourly regular site activities (lighting, security systems, etc.) according to Table 2.

The simulation model illustrated in Fig. 4 was developed using Matlab Simulink environment in order to perform power simulations. Fig. 5(a) shows hourly wind and solar energy potentials derived from Capo Vado site reports. This generation profile limits the power provided by HWES in the site simulation. The power consumption profiles used for a home alone and the whole site – includes 15 homes + site administration appliances – are shown in

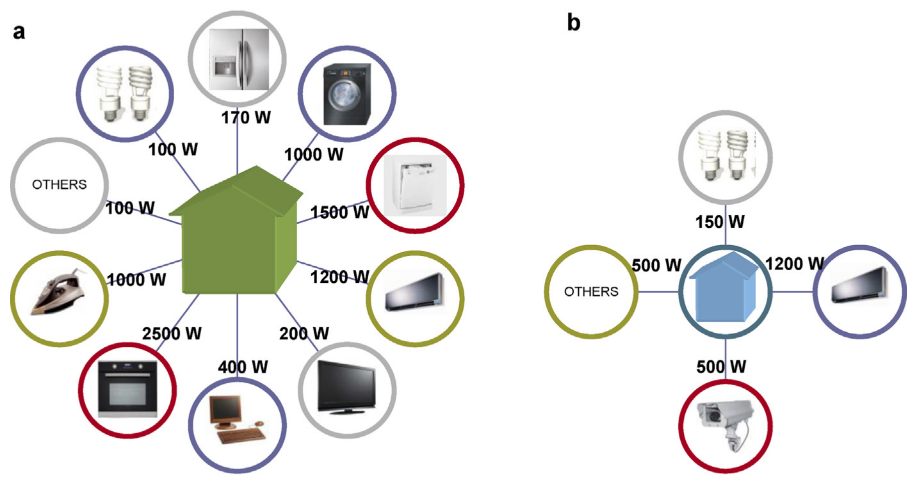

Fig. 3. (a) Regular household appliances and (b) site administration office appliance and serves.

Fig. 5(b) and (c). Because of using the dynamic load model, hourly switching on or off the appliances according to Tables 1 and 2 lead to sharp rise in power demand of the site. Due to large computational complexity and memory requirements of the simulation, 0.1 s is conducted for each hour of day.

Voltage stability, phase and magnitude relevance of three phase sinusoidal voltage, is an important indicator for the evaluation of power quality when using intermittent renewable sources such as wind turbines and solar panels. Fig. 5(d) demonstrates the voltage stability at the site distribution while the site demand introduced very sharp rises. Sinusoidal waveform of phase b and c showed minor deformation at the moment of sharp rise in site demand at the time 0.7 however this does not cause an electrical fault. Because the phase and amplitude of the sinusoidal voltage does not severely effected. This simulation result demonstrates that the integrated energy station can tolerate these sharp demand rises and preserves power quality in site distribution during the simulations.

Following four test scenarios are simulated in this case study. Power flows from the fluctuating hybrid solar and wind sources and the grid toward dynamic site load are demonstrated in the simulation results. Support rate of the hybrid renewable sources, defined as the ratio of renewable energy (E_R) to total site energy consumption (E_S), is expressed as $S_R = E_R/E_S$. Support rate of the grid, defined as the ratio of grid (E_G) to total site energy consumption (E_S), as $S_G = E_G/E_S$. Support rates are presented for the test scenarios and the grid dependence of power distribution is discussed

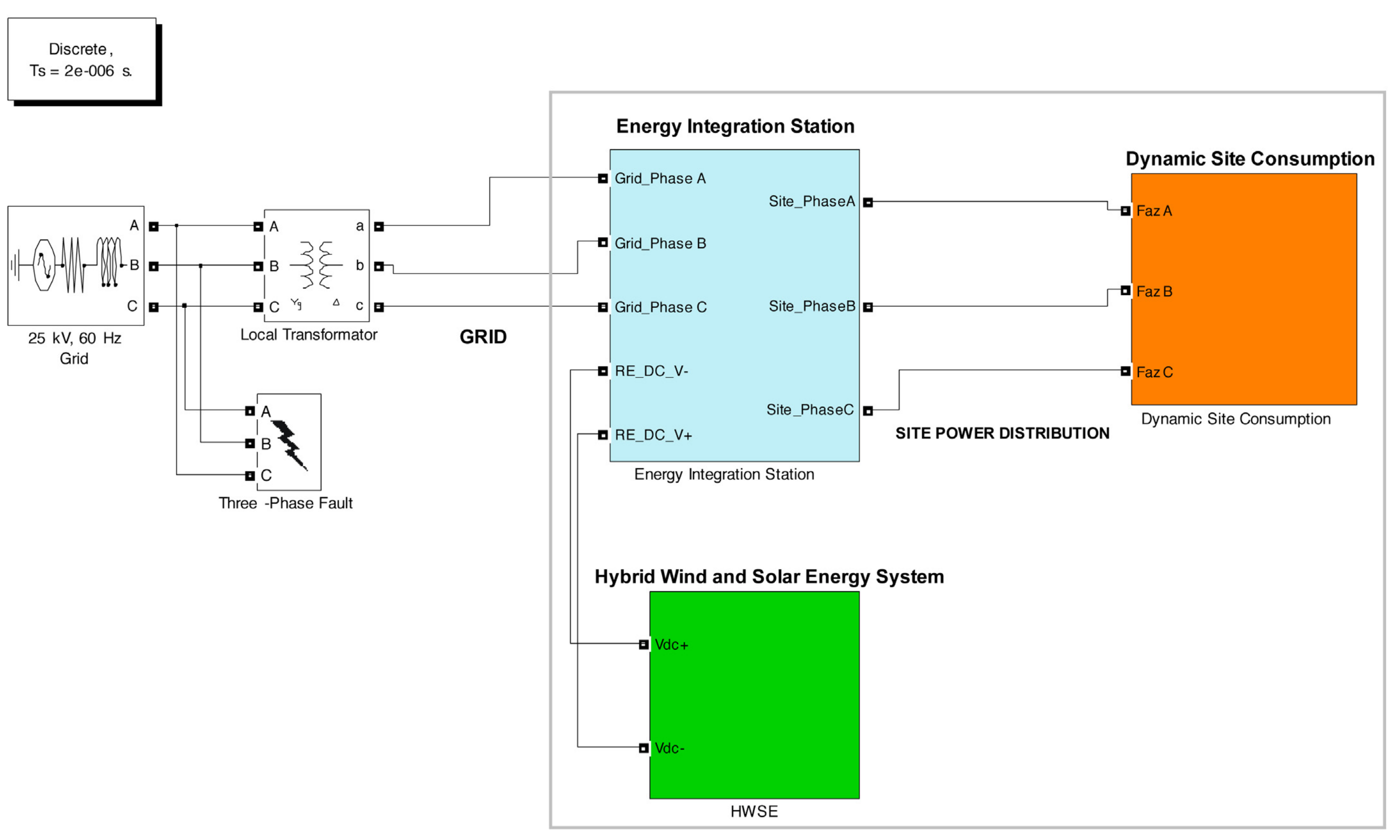

Fig. 4. Matlab Simulink top level simulation models for case studies.

Table 1
Home appliances list used in case study in order to model regular home consumption according to GMT + 2 time domain.

Home appliance	Nominal energy consumption (W)	Home appliance average working schedule (h)
Lighting	150	19–23
Refrigerator	170	0–24
Washing machine	1000	21–22
Dishwasher	1500	20–21
Heating/cooling	1200	0–24
TV	200	07–08/12–13/17–23
Computer	400	17–23
Oven	2500	07–08/12–13/19–20
Iron	1000	21–22
Others	100	0–24

Table 2
Site administration load list used in case study in order to model regular site serves according to GMT + 2 time domain.

Site administration appliance	Nominal energy consumption (W)	Home appliance average working schedule (h)
Lighting	150	19–05
Security systems	500	0–24
Heating/cooling	1200	0–24
Others	500	8–18

for several energy generation potential (high, medium and low levels).

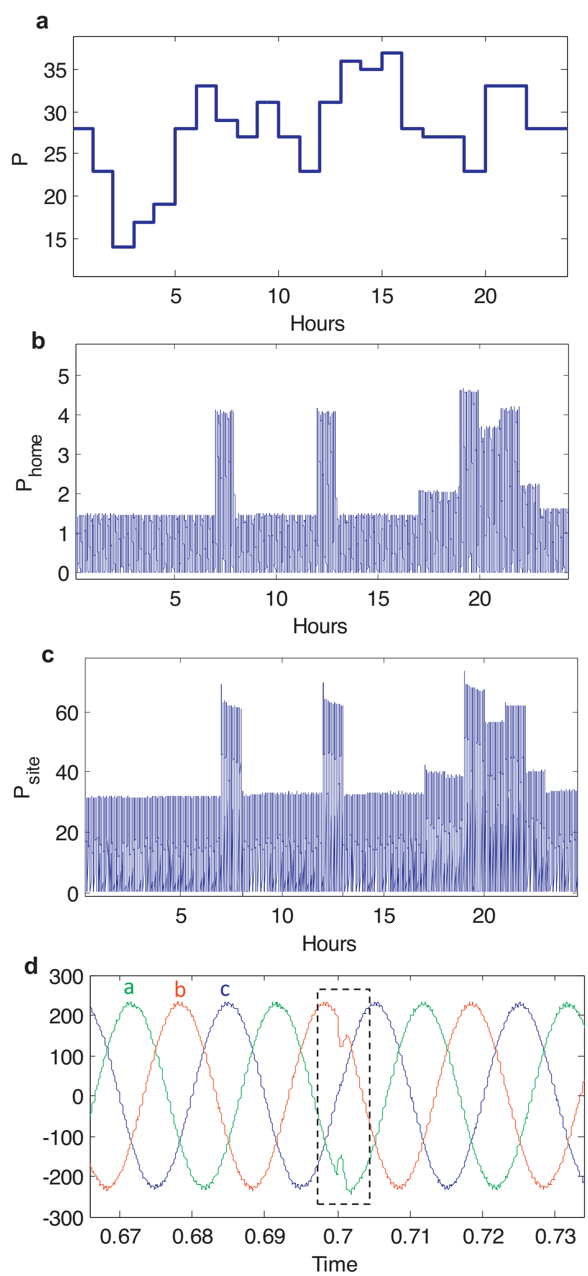

Fig. 5. (a) Hourly wind and solar energy potential (kW) used in simulations. (b) The power demand profile in kW for a home consumption simulation. (c) The power demand profile in kW for the site consumption simulation. (d) Three phase voltage distribution inside the site while a sharp rise in demand is appeared at 0.7 s.

3.1. Full power Capo Vado site generation scenario

Solar and wind generation is assumed to be at levels of Capo Vado site power reports. This test refers to the case of a smart site with a high as possible renewable energy generation potential.

Fig. 6 shows the simulation results from the test scenario of full power Capo Vado site generation. For a possible site power demand shown in Fig. 5(c) given above, the temporal power of the grid and hybrid renewable sources are shown in Fig. 6(a) and (b). The hybrid renewable energy support rate (S_R) was obtained as about 0.92 and the grid energy support rate (S_G) was about 0.08 in the overall site consumption. While the derived temporal power peaks due to the demand of site, the energy integration station preserves the power quality in the site power distribution by deriving the required energy from the grid. In this way site can work self-supportive (islanded mode) in the rest of hours. That is, the renewable energy generation potential of Capo Vado site supplies the most of energy demand to the simulated site and reduces energy dependence of the site appliance to grid energy.

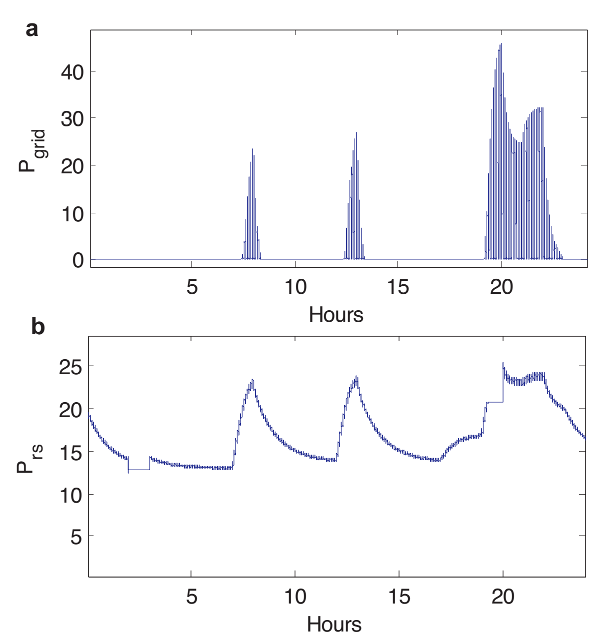

Fig. 6. (a) Instant power (kW) drawn from the grid for the full power Capo Vado site generation scenario and (b) instant power (kW) drawn from the HWES for the full power Capo Vado site generation scenario.

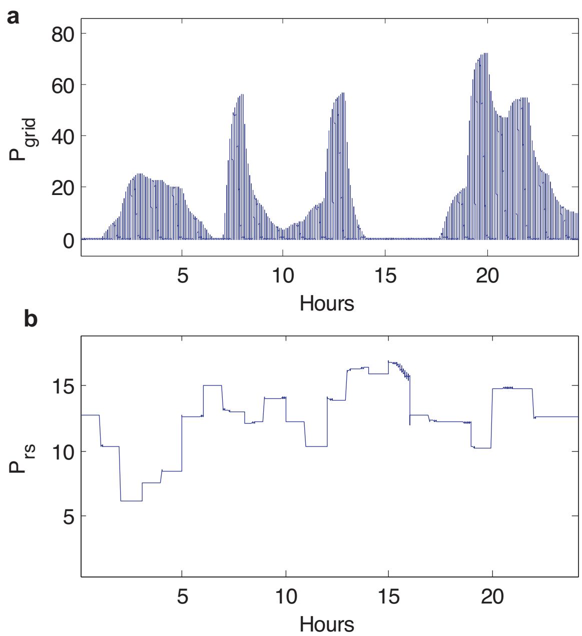

Fig. 7. (a) Instant power (kW) drawn from the grid for the half power Capo Vado site generation scenario and (b) instant power (kW) drawn from the HWES for the half power Capo Vado site generation scenario.

3.2. *Half power Capo Vado site generation scenario*

Solar and wind generation is assumed to be at half levels of Capo Vado site power reports. This test refers to the case of a smart site with medium renewable energy generation potential.

For the site power demand shown in Fig. 5(c), the power drawings of the grid and hybrid renewable sources are shown in Fig. 7(a) and (b). The support rate of hybrid renewable sources (S_R) was about 0.70 and the grid support rate (S_G) was about 0.30 in the overall site energy consumption. Site can work self-supportive (islanded mode) between 14:00 and 17:00 h. A half renewable generation of Capo Vado site can considerably reduce the dependence of the site to grid energy.

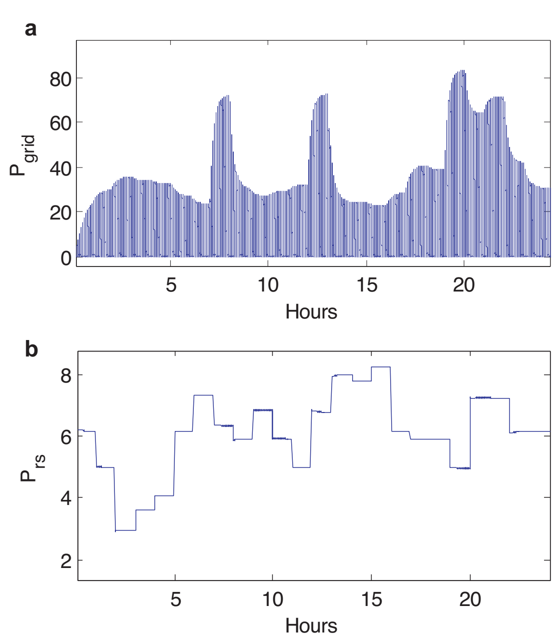

Fig. 8. (a) Instant power (kW) drawn from the grid for a quarter power Capo Vado site generation scenario and (b) instant power (kW) drawn from the HWES for a quarter power Capo Vado site generation scenario.

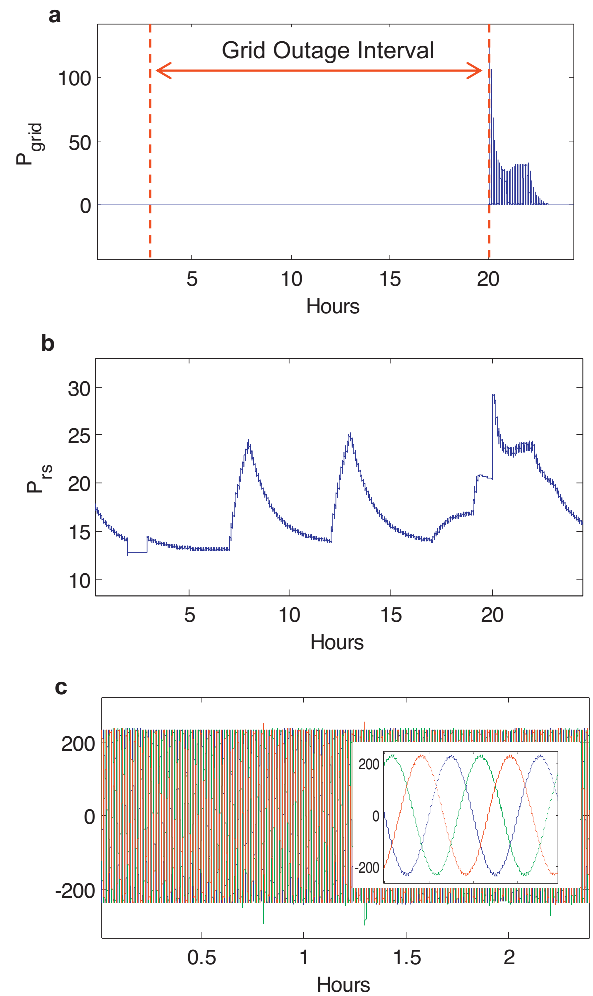

Fig. 9. (a) Instant power (kW) drawn from the grid for the full power Capo Vado site generation scenario, (b) instant power (kW) drawn from the HWES for the full power Capo Vado site generation scenario and (c) three phase voltage measured in the smart site simulation during the grid outage.

3.3. *A quarter power Capo Vado site generation scenario*

Solar and wind generation is assumed to be at quarter levels of Capo Vado site power reports. This test refers to the case of a smart site with low renewable energy generation potential.

For the site power demand shown in Fig. 5(c), the power drawings of the grid and hybrid renewable sources are shown in Fig. 8(a) and (b). The HWES support rate (S_R) and the grid support rate (S_R) were about 0.34 and 0.66, respectively. Despite the fact that a self-support operation is not possible in this scenario, it was seen that the hybrid renewable generation can supply about 30% of the overall site consumption.

3.4. *Grid faults test scenario*

A 17 h grid power interruption due to fault case in grid power distribution was tested in full power Capo Vado site scenario. Advantages of HWES for energy reliability were demonstrated in this simulation.

Fig. 9(a) shows instant power coming from the grid utility. Between 3.00 and 20:00 h, there was an outage in the grid and

Table 3
Energy supports rates calculated from simulation of the test scenarios.

Generation potentials	S_R (%)	S_G (%)	CO_2 emission reduction rates (%)
High level (full power Capa Vado site generation)	92	8	98
Medium level (half power Capa Vado site generation)	70	30	74
Low level (quarter power Capa Vado site generation)	34	66	36

therefore there was not any energy support from the grid to site consumption in these hours. Fig. 9(b) shows the power drawing from the HWES. Due to the outage in the grid, energy integration station draws more power from HWES to meet the energy demand of the site. Three phase voltage levels seen in Fig. 9(c) reveal that the main site appliances can work during the grid fault period and the voltage stability in the site distribution can be preserved. Continuous energy mixing of the grid and renewable energy sources can tolerate energy interruption and fluctuation in some degrees and, considerably preserve power quality in the site distribution. Therefore, HWES improves the energy reliability in the site because of the multiple energy source usage.

This case study shows that,

- Grid dependence of domestic demand can be decreased depending on efficiency of HWES. It is possible to implement self-supportive hours for the site consumption.
- Continuous DC energy mixture enhances power quality and voltage stability of HWES so that it can be supported by the grid energy in inefficient HWE hours. Faults in grid can be tolerated by HWES in inefficient hours and by using intelligent energy management algorithm. This enhances self-healing capability of energy infrastructure.
- More reliable and sustainable energy distribution can be possible by site level HWES integrations in near future smart grid architectures.

4. Conclusions

This study demonstrates that hybrid renewable energy source integration in smart sites can reduce the energy dependence to the grid energy. Energy balance between the site consumption and HWES can be possible in productive generation hours and this allows self-supportive (islanded mode) working hours of site. When the HWES is not enough to supply the site load, grid power supports the site consumption by using the continuous DC energy mixing and provides persistent energy balance in the site. Table 3 summarizes the energy support rates of renewable sources and the grid in the overall site consumption. CO_2 emission reduction in site power consumption is one of the main concerns of distributed HWES utilization. Table 3 also reveals the possible contribution of smart site HWES installation to prospects for CO_2 emission reduction. The CO_2 emission reduction rates is predicted under assumptions of the grid energy generated from fossil fuels fully, zero CO_2 emission from HWES and overall energy loses of 7% from generation, transmission, distribution, etc. In this case, renewable energy rate in consumption plus gain from energy loses indicates CO_2 emission reduction rates, which is calculated by using the formula of $(0.07S_R + S_R)$.

Smart site using a continuous mixing of grid energy and HWES can provide a feasible way for implementation of the renewable energy distributed generation in future smart grids. Installation and maintenance burden of renewable sources decreases in site level integration compared to stand alone home installation and maintenance.

In addition to more clean and more efficient energy potentials of the hybrid renewable sources, renewable energy integration to power distribution can enhance the voltage stability and power quality in the site consumption. Continuous DC energy mixing isolates the domestic appliance from the possible grid faults and voltage instabilities. Moreover, HWES can continue supplying the site appliance at the grid outage, and relief the negative effect of outages on social life standards.

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