Small Solar Panels Can Drastically Reduce the Carbon Footprint of Radio Access Networks

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Extended Abstract

We use a Markov reward process model to study a base station (BS) power system combining a small area solar panel and a battery with a connection to the power grid, with the objective of increasing the amount of green energy used to run the BS and reducing the operator OPEX. The BS power system is controlled by an energy management unit (EMU) that is connected to the BS, the solar panel, the battery, and the power grid. During periods of production of the solar panel, the EMU uses the generated power to run the BS. If the generated power is less than necessary, power is drained from the battery. If the generated power is more than necessary, the excess power is directed to the battery. If the power generated by the panel is insufficient to run the BS and the battery is depleted, power is acquired from the grid. Brown energy can also be drawn from the grid in periods of low energy cost to recharge the battery for later use.

Different energy production levels and BS consumption values are possible based on the weather and of the time of the day and are represented, in our model, by the state of the Markov chain. The reward describes as a continuous variable the battery charge, that in previous studies was shown to be the most critical system element as regards quantization [1].

We investigate the behavior and performance of the BS power system over the 4 seasons, by considering the city of Torino, Italy, at 45 degrees North, where the impact of seasons is significant. The energy entering and exiting the battery is subject to losses, that we assume equal to 15% at both the battery input and output. We show that small solar panels (of the order of 1-2 kW peak, i.e., about 5-10 m^2) combined with limited capacity energy storage (of the order of 10-15 kWh, corresponding to about 3-5 lead acid, 12 V, 120 Ah, car batteries), and a smart energy management policy, can lead to an effective exploitation of renewable energy. That is, to systems where the probability of the battery being empty remains low, so that the amount of energy acquired from the grid is small, and the probability of the battery being full does not grow too high, so that the amount of energy produced by the solar panel that is wasted because it cannot be stored in the battery is small.

The power consumption of a LTE macro BS with 3 sectors, 2x2 MIMO, operating over 20 MHz is derived considering the forecast consumption of BSs in year 2020 [2]. The temporal variation of the power consumption is driven by the BS traffic profiles. For the latter we use real traces provided by an Italian mobile network operator [1]. The energy production stochastic model is derived from two traces available in the Solar Radiation Data (SoDa) website for the city of Torino, Italy. The first (long-term) trace contains daily average irradiance values, collected from January 1st 1985 to December 31st 2005. The second (short-term) trace contains hourly average irradiance values, collected from February 1st 2004 to December 31st 2006. For each season, from the long-term irradiance data we generate the average daily energy production of a 1 kW peak solar panel, and we compute an energy production histogram by applying an equal-range discretization. Using the short-term irradiance data we model the hourly energy production.

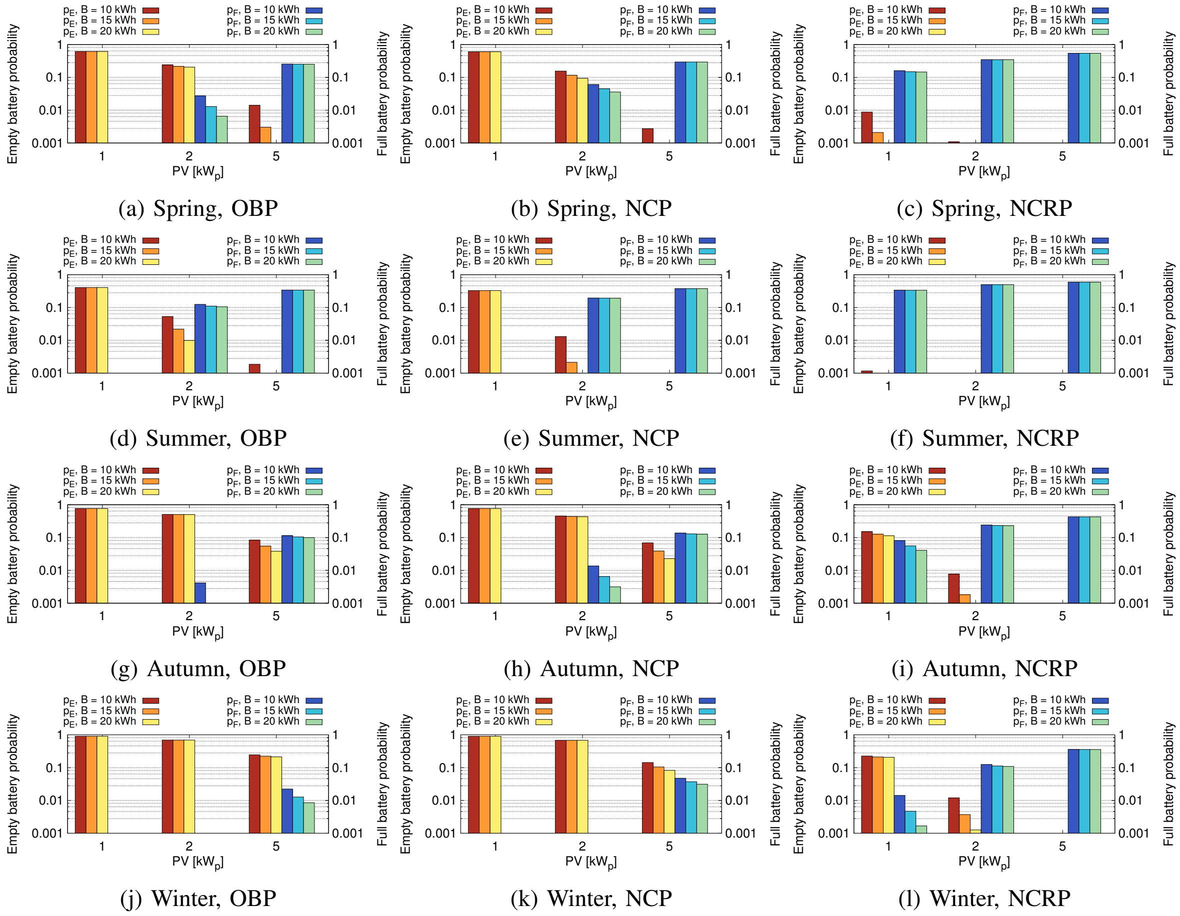
We define a discrete-time Markov chain (DTMC) reward model for each season, over time slots of duration set to 1 h in accordance to the time granularity of our data about solar irradiance and traffic, and to the findings in [1]. Each state is defined by the weather day-type, daytime and solar irradiance level. The battery charge level is captured by an accumulated reward random variable. Roughly speaking, in each state the reward varies according to the amount of energy drained from or stored in the battery. This amount depends on the produced energy that is a random variable. The numerical solution of the reward model exploits the method introduced by Ramaswami et al. in [3]. It creates coupled queues on a common probability space, by using a sequence of “spatial uniformizations”, rather than the usual “time uniformization” technique [4].

The numerical results report the values of empty battery probability, P_e, and full battery probability, P_f, for the four seasons, for the residential traffic profile, and for the following three policies for brown energy acquisition.

Only-battery policy (OBP). Brown energy is acquired only when green energy is not available to run the BS, from neither the PV panel nor the battery.

Night-consumption policy (NCP). Brown energy is acquired from the grid in the interval from midnight to 6 am, in a quantity equal to what necessary to run the BS, so that no energy is drained from the battery in this period; in addition, brown energy is acquired also in other periods of the day whenever green energy is not available to run the BS.

Night-consumption-and-recharge policy (NCRP). Brown



(a) Spring, OBP (b) Spring, NCP (c) Spring, NCRP

(d) Summer, OBP (e) Summer, NCP (f) Summer, NCRP

(g) Autumn, OBP (h) Autumn, NCP (i) Autumn, NCRP

(j) Winter, OBP (k) Winter, NCP (l) Winter, NCRP

Fig. 1: Empty and full battery probability in different seasons, under the considered energy management strategies.

energy is acquired from the grid, in the interval from midnight to 6 am, in a quantity equal to what necessary to run the BS plus 1 kWh per hour; as before, brown energy is acquired also in other periods of the day when the BS cannot run on green energy.

We consider three values for the PV panel size: 1, 2 and 5 kWp, and three battery capacities: 10, 15 and 20 kWh.

Results are reported in Fig. 1, in the case of a residential traffic profile. The red/orange/yellow bars in the figures report empty battery probabilities, while the blue/green bars report full battery probabilities. In Spring, as expected, by increasing the PV panel size, P_e decreases while P_f grows. A small PV panel of 1 kWp is not enough to guarantee a small P_e, meaning that, frequently, brown energy from the grid must be purchased. The opposite happens with a PV panel of 5 kWp: the battery is often full and rarely discharged. When some energy is taken from the grid during night (with the night-consumption and night-consumption-and-recharge policies) P_e becomes negligible, meaning that brown energy is never purchased when it is expensive. The case of a 2 kWp PV panel has an intermediate performance. Similar conclusions can be drawn from the summer season. In this case, due to the higher irradiance, reducing P_e is even easier than in spring. In autumn, since the irradiance is much smaller than in spring or summer, the only-battery and night-consumption policies cannot provide small P_e; even with a 5 kWp panel the battery is frequently discharged and rarely full. The battery regularly fills only under the night-consumption-and-recharge policy. In winter this phenomenon is even more noticeable.

Two main conclusions can be drawn from these results. First, in order to optimize the use of an hybrid PV/grid power supply system, a smart energy management strategy should adopt policies that change based on the season. Second, with a smart energy management strategy, even small PV panels, of about 10 square meters, and few batteries are enough for a green BS operation. This makes the deployability of green BSs much easier, even in urban environments, an interesting conclusion in view of the expected network densification.

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