Algorithm Accelerations for Luminescent Solar Concentrator-Enhanced Reconfigurable Onboard Photovoltaic System

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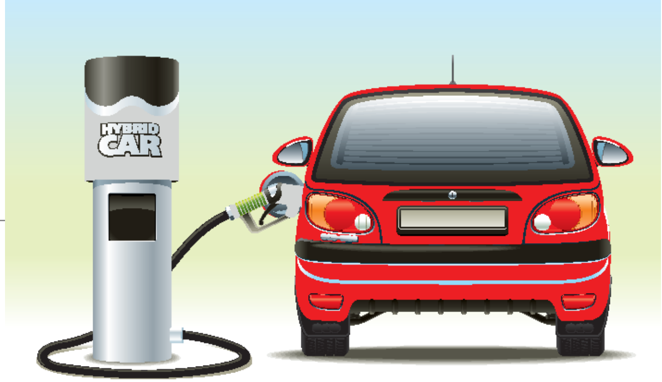
Outline

- Onboard Photovoltaic (PV) Systems for EV/HEV
- Luminescent Solar Concentrator (LSC) Device and LSC-Enhanced PV Cells
- LSC-Enhanced Reconfigurable Onboard PV System for EV/HEV
- Reconfiguration Algorithm Acceleration
- Experimental Results
- Conclusion

Onboard Photovoltaic (PV) Systems for EV/HEV



- EV/HEV are becoming popular
  - Employ electricity to provide supplementary or primary propulsion for the vehicles
  - Their potential for reduced operating costs, petroleum savings, and environmental Benefits.
- However, there are certain shortcomings:
  - Batteries have relatively high life-cycle energy consumption cost.
  - The coverage of charging stations for EV/HEV is limited comparing with gas stations.

Onboard Photovoltaic (PV) Systems for EV/HEV

- Photovoltaic (PV) systems can be used on EV/HEV
  - Help propel the vehicle during cruising
  - Charge EV/HEV battery during parking
- However, there are certain shortcomings:
  - The rigid surface of PV cells does not fit well with the streamlined surface of modern vehicles
  - The dark blue color of PV cells may not satisfy the aesthetic standards of modern vehicles
  - The energy efficiency is not high, at most 15% propelling power for state-of-the-art vehicle

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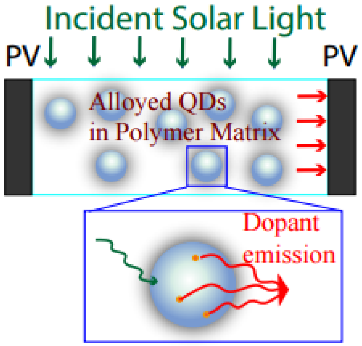
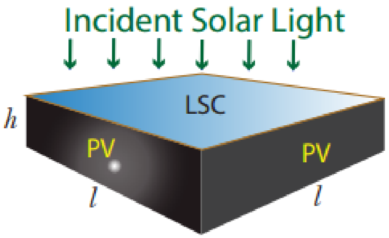
Luminescent Solar Concentrator (LSC) Device and LSC-Enhanced PV Cells

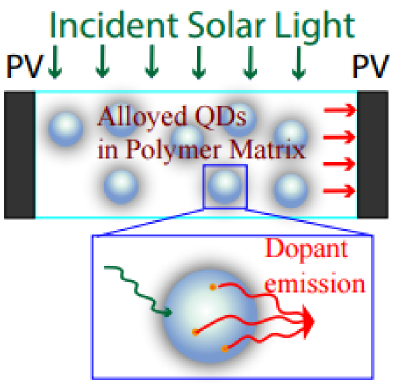
- Luminescent solar concentrator (LSC) devices are magnetically doped by quantum dots (QDs), which can absorb and emit both direct and diffuse sunlight onto the surrounding PV strips to significantly enhance the utilization of solar energy.

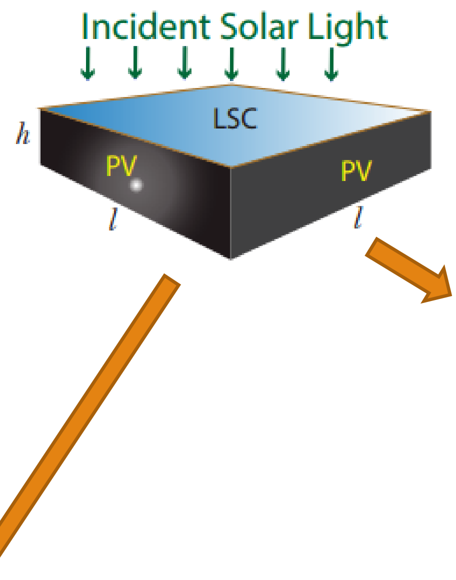


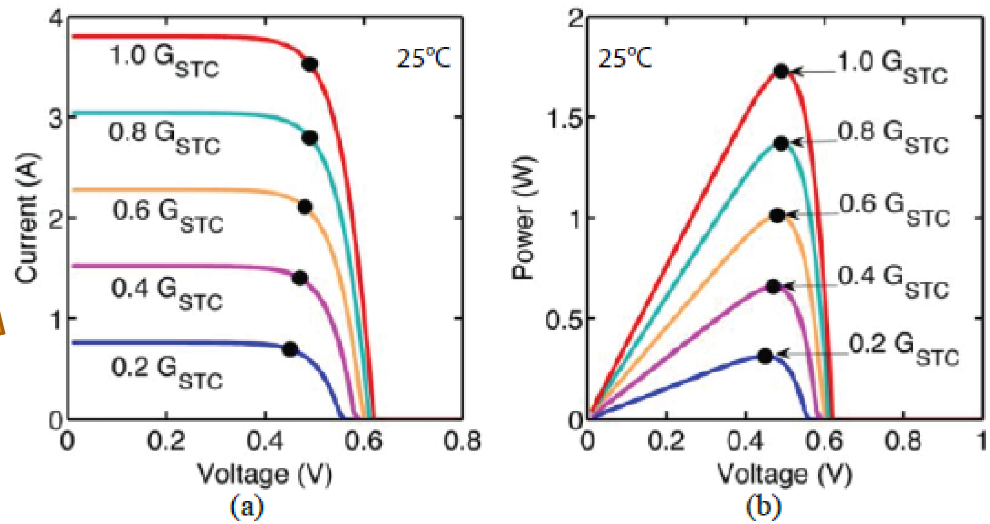


- It can implement an LSC-enhanced PV cell with a surrounding “PV strip”
- LSC-enhanced PV cells are transparent and flexible and well-fit for modern EV/HEV
- They can provide higher efficiency due to the switched spectrum and reduced thermal effects
- They are cheaper in capital cost compared with normal PV cells

Luminescent Solar Concentrator (LSC) Device and LSC-Enhanced PV Cells







(a) Voltage-current (V-I) and (b) voltage-power (V-P) characteristics of the PV strip under different solar irradiances.

PV Strip Characteristics

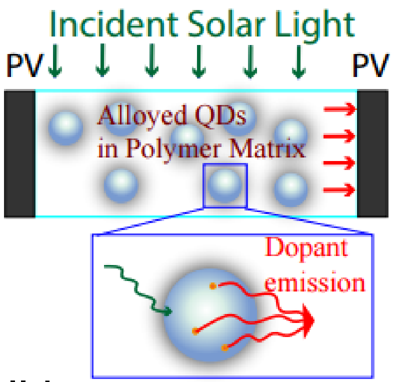
- G_{STC} = 1000W/m^2 (Stands for solar irradiance level under standard test condition)
- The solid black dots stand for the maximum power points (MPPs) in (a),

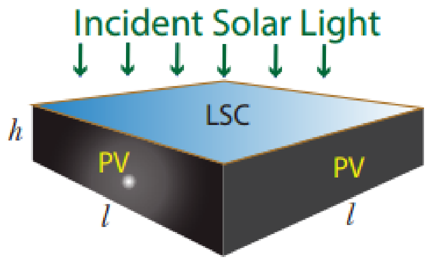
which correspond to the peak power values marked by the black dots in (b).

Luminescent Solar Concentrator (LSC) Device and LSC-Enhanced PV Cells

The solar irradiance level concentrated onto the PV strips is

$$G' = G \times E_{LSC} = G \times \frac{A_t}{A_e} \times \eta_{op}$$





G : direct input solar irradiance level on an LSC-enhanced PV cell.

A_t: top surface area;

A_e: four-side edge surface area.

The output power of an LSC-enhanced PV cell is

$$P_{pv}(G \cdot E_{LSC}) \cdot \frac{A_e}{A_t} \cdot \eta_{misc}$$

P_{pv}(G) : Output power of a conventional PV cell (with the same area as the LSC top surface);

η_{misc} : Correction factor accounting for the shift in the light spectrum and the reduced thermal impact.

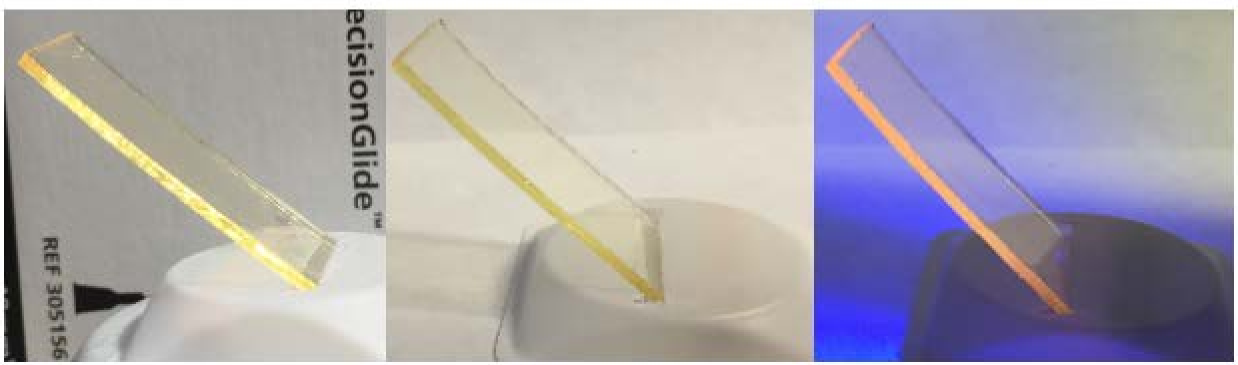
$\eta_{misc} > 1$ in general, because

(i) the light emitted and concentrated from QDs exhibits a shifted spectrum, which can be converted into electric energy by PV strips with a higher efficiency,

(ii) the thermal effect is significantly reduced with LSCs.

Luminescent Solar Concentrator (LSC) Device and LSC-Enhanced PV Cells

Our fabricated LSC polymer devices



(a) (b) (c)

Side view of our fabricated model of the luminescent solar concentrator (LSC) magnetically doped by quantum dots (QDs) under the light sources of (a) sunlight (b) daylight lamp and (c) UV lamp.

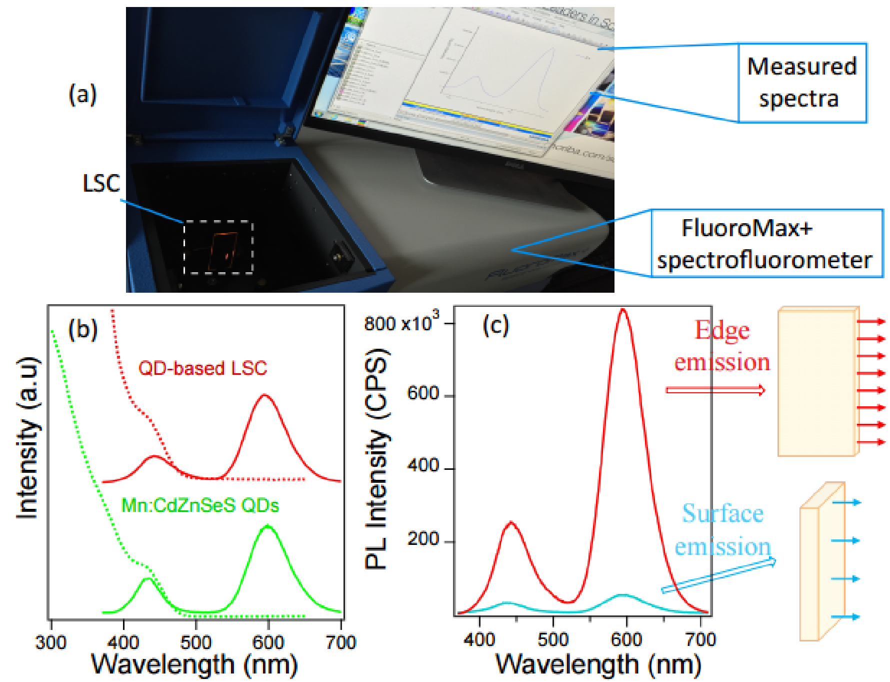
As we can see from the pics, the edges are brighter than the surfaces under different light sources.

Luminescent Solar Concentrator (LSC) Device and LSC-Enhanced PV Cells

(a) shows the picture of our experimental testing platform for angle-dependent photoluminescence (PL) of the selected LSC.

We measure the UV-Visible spectrophotometry (UV-Vis) on an Agilent Cary 60 spectrophotometer between 300 and 700 nm as shown in (b).

We observe that the optical spectra of the nanoparticles in the LSC remain the same as in the organic solution which indicates the excellent nanoparticles stability in the LSC

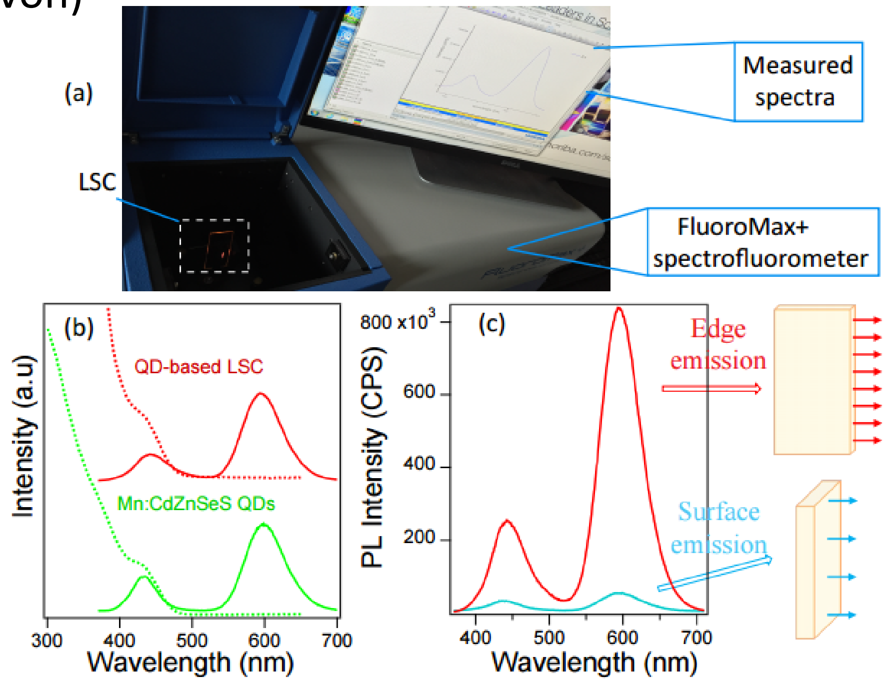


Stability and efficiency testing of the LSC devices

Luminescent Solar Concentrator (LSC) Device and LSC-Enhanced PV Cells

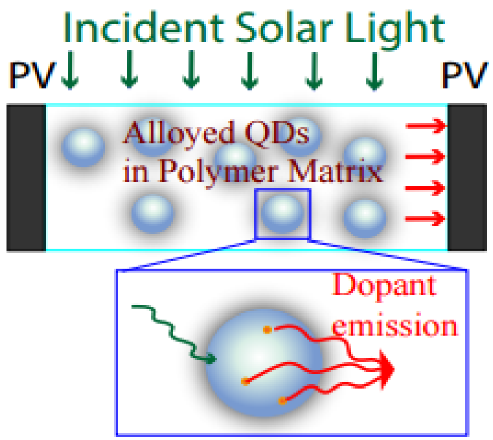
We perform the angle-dependent PL measurement using a FluoroMax+ spectrofluorometer (Horiba Jobin Yvon) shown in (c).

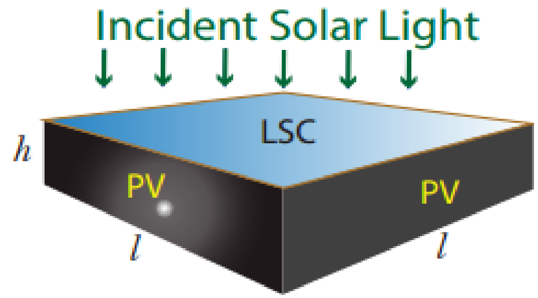
we compare the two PLs when the detector is lined with the edge and the surface of the LSC. The PL spectra clearly indicates the intensity of light emitted from the edge of LSC is an order of magnitude higher than that from the surface of LSC, which proves the light concentration effect at the LSC edge.



Stability and efficiency testing of the LSC devices

Luminescent Solar Concentrator (LSC) Device and LSC-Enhanced PV Cells





We need to optimize the area and thickness at the system design stage

- Minimize capital cost and computational complexity
- Satisfy the constraint on the E_{LSC} value

- A square top surface to ensure identical solar irradiance level.
- *h* ranges from 0.5mm to 2mm with varying LSC surface area.
- If the E_{LSC} value is limited by 5, the upper limit of the LSC surface area will be 0.04 m^2.

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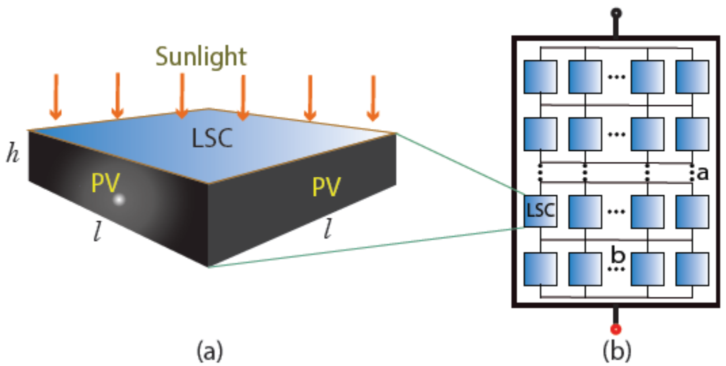
LSC-Enhanced Reconfigurable Onboard PV System for EV/HEV

- For the reconfigurable PV array using the conventional PV cells, in the system design stage, PV cells with proper size can be selected to achieve a trade-off between electric connection complexity and PV system performance.
- However, an LSC-enhanced PV cell has an upper limit on its area, i.e., 0.04 m^2, resulting in around or over 200 LSC-enhanced PV cells within the total vehicle surface area of 7 - 8 m^2 from engine hood, trunk, roof, left and right door panels of an EV/HEV.
- In this case, the computational time of PV array reconfiguration algorithm is prohibitive for online applications because the computational complexity is $O(N^3)$ for PV array reconfiguration, where N is the number of PV cells. Moreover, the number of integrated programmable switches will also be large and therefore the capital cost will be high. In order to reduce the computational complexity and capital cost, we propose the concept of LSC-enhanced PV macrocell.

LSC-Enhanced Reconfigurable Onboard PV System for EV/HEV

LSC-Based PV Macrocell and PV Array Reconfiguration:



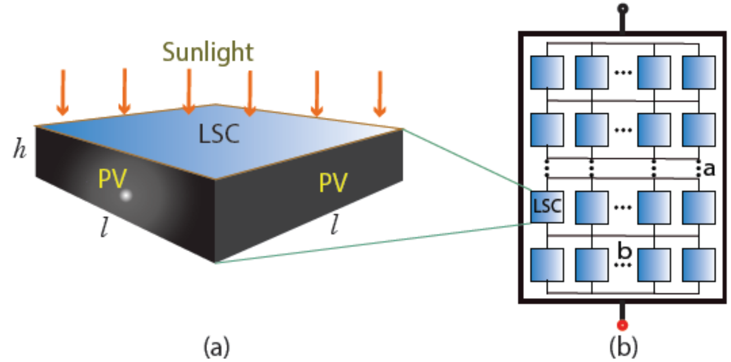
Structures of (a) an LSC-enhanced PV cell and (b) an LSC-based PV macro-cell.

The macrocell has a size of a x b (a LSC-enhanced PV cells connected in series and b PV cells connected in parallel).

- a x b refers to the internal electrical connections instead of physical layouts. Different macrocells may have different physical layouts, although they have the same size of a x b.
- We employ the macrocell as the basic unit for the PV array reconfiguration, i.e., electric connections among macrocells may be changed during reconfiguration, while the internal electric connections within each macrocell are fixed at the system design stage.

LSC-Enhanced Reconfigurable Onboard PV System for EV/HEV

LSC-Based PV Macrocell and PV Array Reconfiguration:



Structures of (a) an LSC-enhanced PV cell and
(b) an LSC-based PV macro-cell.

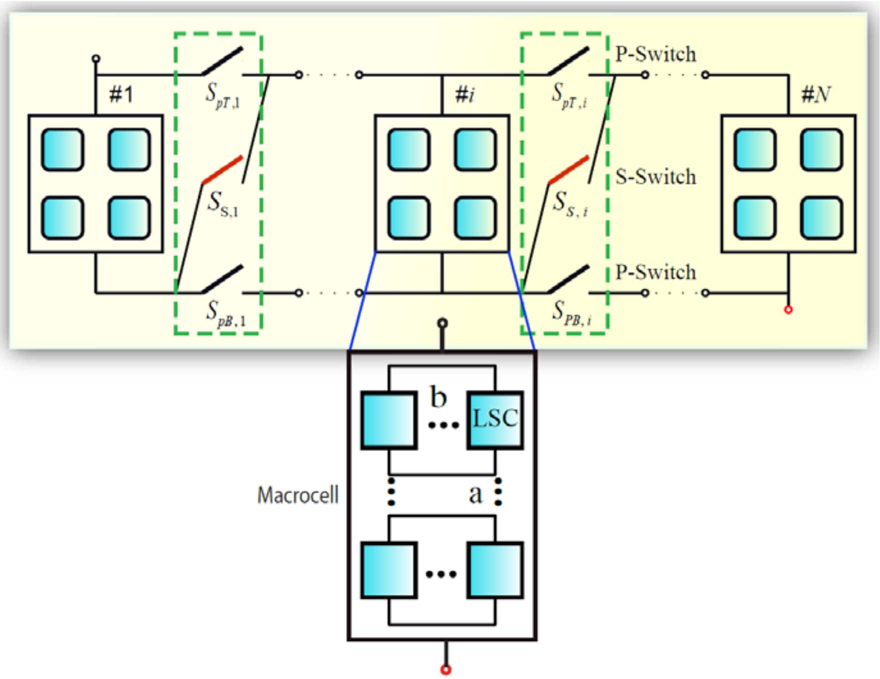
LSC-based PV macrocell

- Reduce the computational complexity and capital cost;
- Different macrocells may have different physical layouts;
- The internal electric connections within the macrocells are fixed at the system design stage.

LSC-Enhanced Reconfigurable Onboard PV System for EV/HEV

LSC-Based PV Macrocell and PV Array Reconfiguration:

- Reconfigurable LSC-enhanced PV array consists of N macrocells mounted on the hood, roof, trunk, and door panels of an EV/HEV.
- Each *i-th* macrocell is integrated with three insular-gate bipolar transistor (IGBT) switches: a top parallel switch $S_{pT,i}$, a bottom parallel switch $S_{pB,i}$, and a series switch $S_{s,i}$.
  - The parallel switches connect macrocells in parallel forming marcocell groups, while the series switches connect macrocell groups in series forming a PV array configuration.
- The three switches of a macrocell are in one of the two states:
  - (i) parallel connection when $S_{pT,i}$ and $S_{pB,i}$ are ON while $S_{s,i}$ is OFF,
  - (ii) series connection when $S_{pT,i}$ and $S_{pB,i}$ are OFF and $S_{s,i}$ is ON.

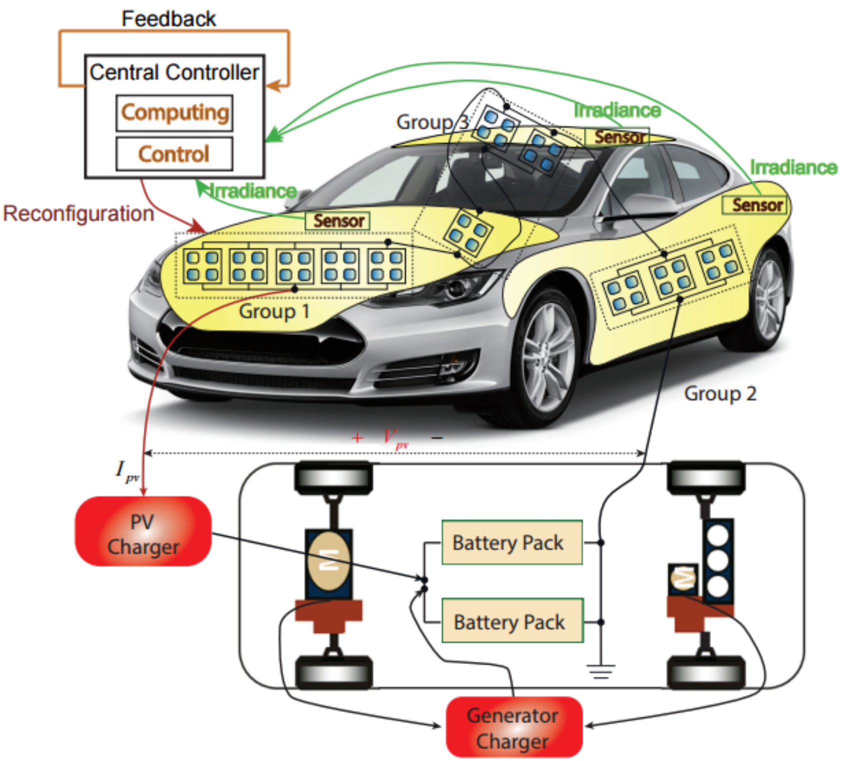


Macrocell-based reconfigurable PV array

By controlling the ON/OFF states of the switches, the reconfigurable LSC-enhanced PV array changes its internal connections of macrocells (i.e., configuration).

LSC-Enhanced Reconfigurable Onboard PV System for EV/HEV

LSC-Enhanced PV Array Reconfiguration Algorithm

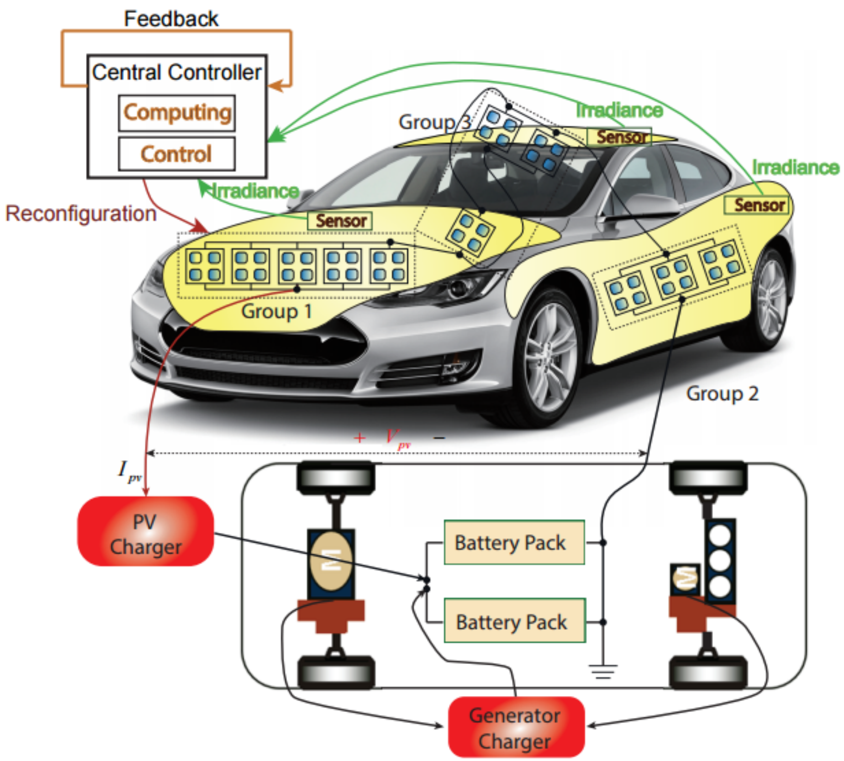


System diagram of an LSC–enhanced reconfigurable onboard PV system.

- With given PV array design (fixed macrocell size), the PV array reconfiguration algorithm is performed periodically to dynamically derive the optimal configuration of the PV array such that the PV array always provides the maximum charging current to the battery under changing solar irradiance levels on vehicle panels.

LSC-Enhanced Reconfigurable Onboard PV System for EV/HEV

LSC-Enhanced PV Array Reconfiguration Algorithm



System diagram of an LSC−enhanced reconfigurable onboard PV system.

The algorithm has

Outer loop:

- find the optimal macrocell group number *g*;

Algorithm 1: The Outer Loop

Input: The number of macrocells N, solar irradiance G_i on each macrocell, and battery pack voltage V_{batt}.

Output: The optimal configuration C^{opt} of the LSC-enhanced PV array.

Calculate the MPP voltage V^{pvc}_{MPP} and the MPP current $I^{pvc}_{MPP}(G_i)$ of each LSC-enhanced PV cell.

for *g from 1 to N* **do**

  Find $C^{opt}(g)$ by Algorithm 2.

  Calculate battery charging current I_{batt} based on the converter model, $C^{opt}(g)$, and V_{batt}.

  if $I_{batt} > I^{max}_{batt}$ **then**

    $I^{max}_{batt} \leftarrow I_{batt}$

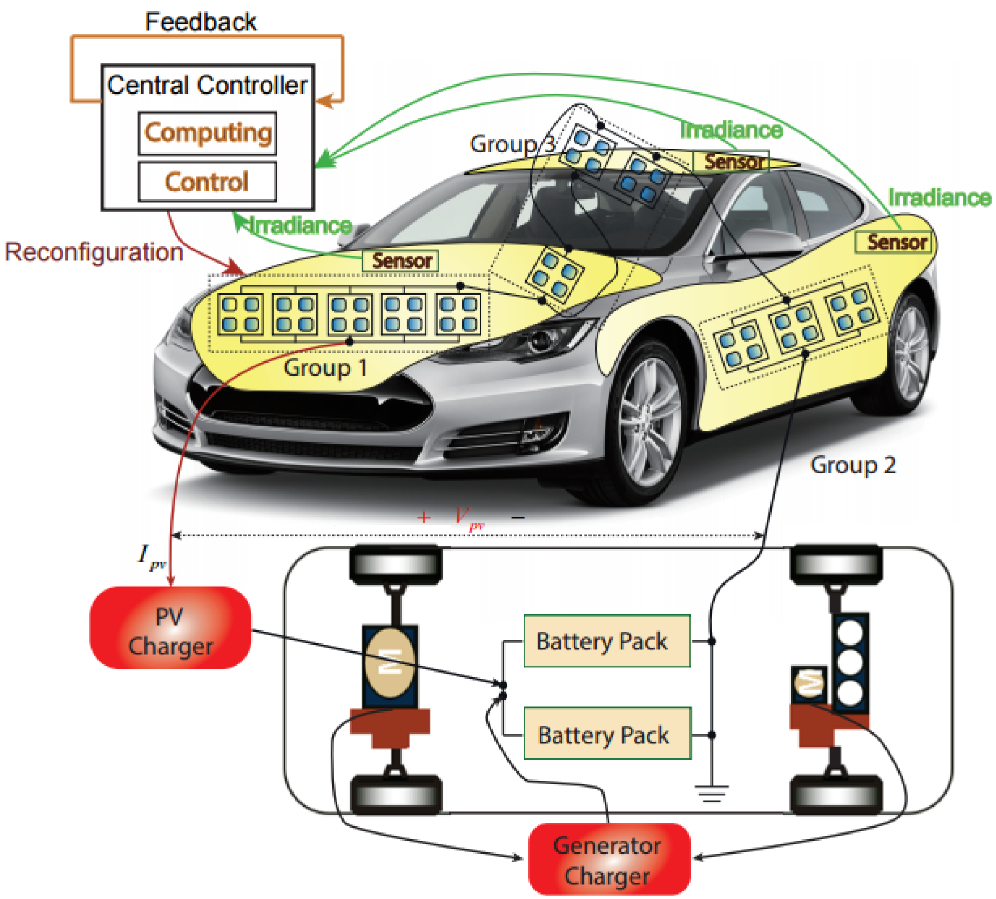
    $C^{opt} \leftarrow C^{opt}(g)$

  end

end

LSC-Enhanced Reconfigurable Onboard PV System for EV/HEV

LSC-Enhanced PV Array Reconfiguration Algorithm



The algorithm has

Kernel algorithm:

- find the optimal PV array configuration under the given g value from the outer loop

Algorithm 2: The Kernel Algorithm

Input: V_{MPP}^{pvc}, $I_{MPP}^{pvc}(G_i)$, V_{batt}, and g.
Output: The optimal configuration $C^{opt}(g)$ of the LSC-enhanced PV array.
Maintain two $N \times g$ matrices **Min_Sum_Opt** and **Last_Par**.
Initial **Min_Sum_Opt**$(l_1, 1) \leftarrow \sum_{1 \le i \le l_1} b \cdot I_{MPP}^{pvc}(G_i)$.
Initial **Last_Par**$(l_1, 1) \leftarrow 0$.
for l_2 *from 2 to* g **do**
  for l_1 *from* l_2 *to* N **do**
    Min_Sum_Opt$(l_1, l_2) \leftarrow$
    $\max_{l_2-1 \le l < l_1} min\{$**Min_Sum_Opt** $(l, l_2 - 1), \sum_{l < i \le l_1} b \cdot I_{MPP}^{pvc}(G_i)\}$
    Last_Par$(l_1, l_2) \leftarrow$
    $argmax_{l_2-1 \le l < l_1}\, min\{$**Min_Sum_Opt** $(l, l_2 - 1), \sum_{l < i \le l_1} b \cdot I_{MPP}^{pvc}(G_i)\}$
  end
end
Trace back using the matrix **Last_Par** to find the optimal configuration $C^{opt}(g)$ of the LSC-enhanced PV array.

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Reconfiguration Algorithm Acceleration

The optimal PV reconfiguration algorithm described in the previous Section has relatively high computation and implementation complexities, and hence, we introduce two specific scenarios that lead to both simplification and acceleration on the optimal PV reconfiguration algorithm for the LSC-enhanced PV array.

Scenario I: Partial Shading Simplification

Scenario II: Charger Efficiency Simplification

Reconfiguration Algorithm Acceleration

Scenario I: Partial Shading Simplification

Assumption: PV macrocells are either completely shaded (i.e., G_{zero}) or lighted (i.e., $G_{lighted}$).

Reason: Solar irradiance on a shaded macrocell for a standalone LSC-enhanced PV system is often reduced by more than 10 × when comparing with a lighted macrocell (this scenario would be a valid approximation.)

- Consider the general case where $N_{lighted}$ out of the total N macrocells in the PV array are lighted.
- We aim at finding the number N' ($\leq N_{lighted}$) of activated macrocells and making them an $n' \times m'$ connection (i.e., n' macrocells in series and m' macrocells in parallel), satisfying $n' \times m' = N'$.
- The objective is to maximize the battery pack charging current I_{batt}.

Reconfiguration Algorithm Acceleration

Scenario I: Partial Shading Simplification

In the outer loop, the algorithm finds the optimal *N'*, whereas, in the inner loop, the algorithm finds the optimal $n' \times m'$ connection.

- In the outer loop, the algorithm employs an effective branch & bound heuristic to reduce the search space. The intuition behind the branch & bound algorithm is as follows:

  The optimal *N'* should

  - (i) be enough large and close to $N_{lighted}$ in order to increase the MPP power of the LSC-enhanced PV array,
  - (ii) have a relatively large number of factors since we can then have more choices of $n' \times m'$ connections with this *N'* value.

Algorithm 3: Optimal LSC-Enhanced PV Array Reconfiguration Algorithm in the First Scenario

Input: Solar Irradiance on each macrocell (either $G_{lighted}$ or G_{zero}) and battery pack voltage V_{batt}.
Output: The optimal configuration $C(g; r_1, r_2, ..., r_g)$ of the LSC-enhanced PV array.
Calculate $I^{pvc}_{MPP}(G_{lighted})$ based on the $G_{lighted}$ value.
Derive the proper range of N' using the branch & bound method.
for *each* (N') *in this range* **do**
    for *each* n' *value that is a factor of* N' **do**
        Find the two n' values that result in the best match between input and output voltages of the charger, i.e., $n' \times V^{pvc}_{MPP}$ and V_{batt}.
    end
    Calculate I_{batt} based on the input voltage $n' \times V^{pvc}_{MPP}$, input current $m' \times I^{pvc}_{MPP}(G_{lighted})$, and output voltage V_{batt} of the charger.
    Determine the optimal n' (and corresponding m') value.
end
Determine and return the optimal N' value.

Reconfiguration Algorithm Acceleration

Scenario I: Partial Shading Simplification

- Hence in the heuristic, we find all the $N' \leq (N_{lighted})$ values satisfying $N' + Factor(N') \geq N_{lighted}$, where $Factor(N')$ returns the number of factors of integer N'. We only perform the inner loop, i.e., finding the optimal $n' \times m'$ connection on this chosen set of N' values.
- In the inner loop, the algorithm either chooses the two n' values (factors of N') that result in the best match between the input and output voltages of the charger, i.e., the MPP voltage $n' \times V_{MPP}^{pvc}$ of LSC-enhanced PV array and the battery pack voltage V_{batt} are closest to each other, or performs the ternary search algorithm to derive the optimal $n' \times m'$ connection.

We then perform MPTT control to find the optimal operating point (V^{pvp}, I^{pvp}) of the PV array. The MPTT control is performed much more frequently than PV reconfiguration to keep tracking the optimal operating point of the LSC-enhanced PV array.

Reconfiguration Algorithm Acceleration

Scenario II: Charger Efficiency Simplification

Assumption: the conversion efficiency of the charger is high and nearly constant as long as its input voltage reaches or exceeds a threshold value V_{th} ; the conversion efficiency is low when its input voltage is less than V_{th}. We begin with the following general observation on the desirable number of macrocell groups.

Observation: For the LSC-enhanced PV array configuration, it is desirable to have fewer series-connected macrocell groups if we only want to maximize the MPP power of the LSC-enhanced PV array, i.e., without considering the conversion efficiency variation of the charger. Theoretically, connecting all macrocells in parallel will result in the largest MPP power of the PV array itself, because the MPP power, in this case, is the sum of the MPP power values of all the macrocells of the PV array.

Algorithm 4: Optimal LSC-enhanced PV Array Reconfiguration Algorithm in the Second Scenario

Input: Solar Irradiance on each *macrocell* G_i, battery voltage V_{batt}, and number of macrocell groups g.
Output: The optimal configuration $C(g; r_1, r_2, ..., r_g)$ of the LSC-enhanced PV array.

Calculate V_{MPP}^{pvc} *and* $I_{MPP}^{pvc}(G_i)$ based on the G_i values.
Maintain two $N \times g$ matrices **Min_Sum_Opt** and **Last_Par**.
Initial **Min_Sum_Opt**$(l_1, 1) \leftarrow \sum_{1 \le i \le l_1} I_{MPP}^{pvc}(G_i)$.
Initial **Last_Par**$(l_1, 1) \leftarrow 0$.
for l_2 *from 2 to* g **do**
  for l_1 *from* l_2 *to* N **do**
    Min_Sum_Opt$(l_1, l_2) \leftarrow \max_{l_2 - 1 \le l < l_1} min\{$**Min_Sum_Opt** $(l, l_2 - 1), \sum_{l < i \le l_1} I_{MPP}^{pvc}(G_i)\}$
    Last_Par$(l_1, l_2) \leftarrow argmax_{l_2 - 1 \le l < l_1}\ min\{$**Min_Sum_Opt** $(l, l_2 - 1), \sum_{l < i \le l_1} I_{MPP}^{pvc}(G_i)\}$
  end
end
Trace back using the matrix **Last_Par** to find the optimal configuration $C(g; r_1, r_2, ..., r_g)$ of the LSC-enhanced PV array.

Reconfiguration Algorithm Acceleration

Scenario II: Charger Efficiency Simplification

We intend to use the lowest number of groups that makes the conversion efficiency in the "high" range. In other words, we find the lowest value g satisfying $g \times V_{MPP}^{pvc} \geq V_{th}$, and set this value g as the number of macrocell groups.

We provide the simplified optimal reconfiguration algorithm that derives the optimal configuration $C(g; r_1, r_2, \ldots, r_g)$ to maximize the battery charging current I_{batt}. Details of the algorithm are provided in Algorithm 4 which has a time complexity of $O(g \cdot N^2)$.

We then perform maximum power transfer tracking (MPTT) or maximum power point tracking (MPPT) control using the perturb & observe algorithm.

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Experimental Results

We compare the performance (output power) of the proposed two specific scenarios (Algorithm 3 and Algorithm 4) and the optimal PV array reconfiguration algorithm. For each algorithm, we optimize the macrocell size and the reconfiguration period of the LSC-enhanced reconfigurable onboard PV system. The objective is to maximize the output power of the LSC-enhanced PV system, while satisfying design constraints on LSC size, capital cost and reconfiguration computational complexity, timing and energy overheads, etc.

Experimental Setup

We attach solar sensors to vehicle panels of a sedan Renault-Samsung NEW-SM5 and drive the vehicle to collect the solar irradiance traces.

We measure the areas of the vehicle panels for coating LSC-enhanced PV cells and obtain the following areas: roof: 2.02 m^2, left: 1.7 m^2, right: 1.7 m^2, trunk: 0.63 m^2, hood: 0.62 m^2.

Based on characteristics of LSC-enhanced PV cells from experiments, we optimize the area of an LSC-enhanced PV cell as 0.04 m^2 with an MPP supply voltage of 20 V. The LSC-enhanced PV cell MPP current is around 1.01 A at G=1000 W/m^2. Additionally, we assume the terminal voltage of the EV/HEV battery pack as 200 V and consider a practical PV charger model with charging efficiency variations.

Experimental Setup

Developed solar sensors

The sensing and control loop includes

- solar sensors for sensing the solar irradiance levels on vehicle panels,
- sensor network for coordinating and communicating sensing data,
- computation device to derive the optimal PV array configuration, control mechanism of configuration and operating point of the PV array

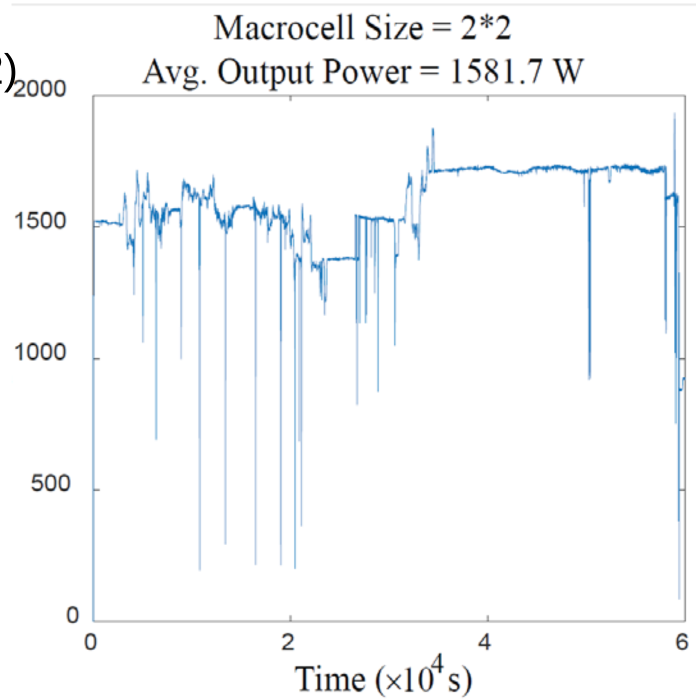
Recorded driving profiles

Location	Start time	End time	Distance
Incheon Airport	12:35	12:43	5.2km
Ontario to Riverside	08:32	08:57	27km
West LA to Indio	12:53	19:50	261.8km
West LA to Carson	14:47	16:31	44.7km
Riverside	14:15	14:36	3.1km
West LA to Riverside	09:58	11:21	112.3km

Experimental Results

Simulation results of optimal PV array reconfiguration algorithm system using measured LSC characteristics and driving profiles

Driving profiles:
Benchmark 2 (B2)



Benchmark	B1	B2	B3	B4	B5
Performance with baseline PV (W)	473.1	936.1	767.2	557.7	951.2
Performance with LSC-enhanced PV (W)	621.8	1230.2	994.9	725.7	1240.2
Performance gain	1.31X	1.31X	1.29X	1.30X	1.30X

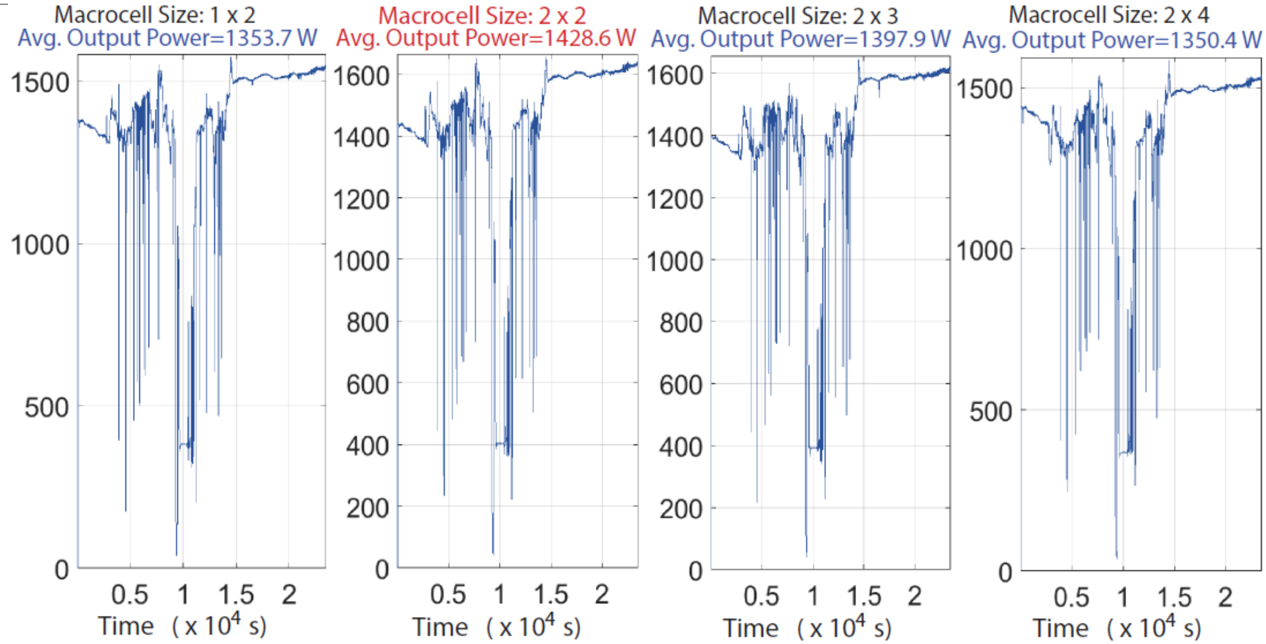
Performanve (Average output power) of the optimal PV array reconfiguration algorithm system and the baseline (tramditon) PV system

- Maximum of 1.31X performance improvement of the optimal PV array reconfiguration algorithm system with LSC-enhanced PV cells comparing with the baseline system.

Future in-system testing

Experimental Results

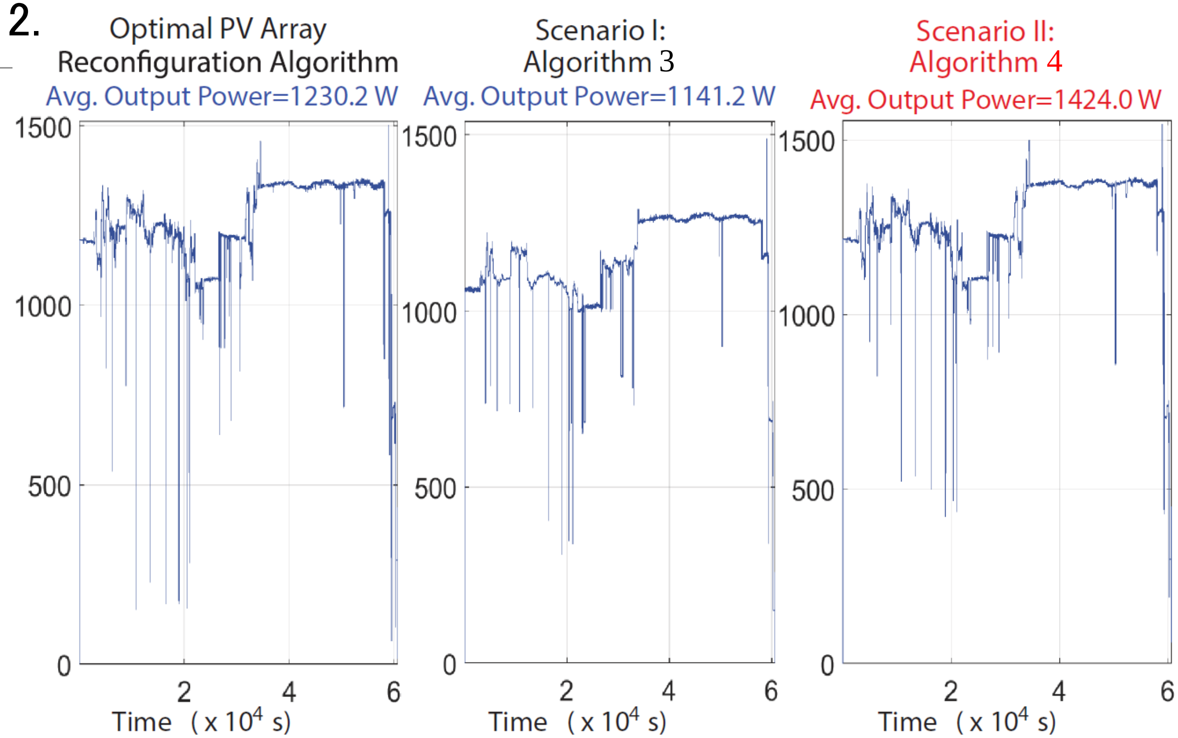
Output power profiles of Scenario 2 with respect to different macrocell sizes using solar irradiance benchmark 5.



After averaging over all the five benchmark solar irradiance traces, we obtain the optimal macrocell size of each algorithm. The optimal macrocell size is 2×2 (2 LSC-enhanced PV cells connected in series and 2 cells connected in parallel) for both optimal PV array reconfiguration algorithm and algorithm 4 (Scenario 2). While the optimal macrocell size is 1×2 for algorithm 3 (Scenario 1).

Experimental Results

Output power profiles of the proposed algorithms in the two scenarios and the optimal PV array reconfiguration algorithm using solar irradiance benchmark 2.



Experimental Results

TABLE I
AVERAGE OUTPUT POWER OF THE PROPOSED TWO ALGORITHMS AND THE OPTIMAL PV ARRAY RECONFIGURATION ALGORITHM [10] WITH THE CORRESPONDING OPTIMAL MACROCELL SIZES.

	Avg. Output Power (W)					Optimal Macrocell
Benchmark	B1	B2	B3	B4	B5	Size (a $\times$ b)
Optimal Algorithm	621.8	1230.2	994.9	725.7	1240.2	2×2
Scenario I: Algorithm 1	571.7	1141.2	799.8	652.9	1029.4	1×2
Scenario II: Algorithm 2	719.9	1424.0	1153.0	840.8	1428.6	2×2

Tab. I summarizes the average output power of profiles of the proposed algorithms in the two scenarios and the optimal PV array reconfiguration algorithm.

- In the first scenario, the output power of algorithm 3 is 9.0% lower in average than that of the optimal PV array reconfiguration algorithm.
- In the second scenario, we observe an average of 1.16X performance improvement of the proposed algorithm 4 comparing with the optimal PV array reconfiguration algorithm.
- Both algorithm 3 and algorithm 4 can significantly reduce the computational overhead and therefore making it easier to satisfy the system design constraints. That’s why they can achieve comparable or even better performance than the optimal algorithm. Algorithm 3 results in a little lower performance than the optimal algorithm due to the over simplification of the solar irradiance levels.

Outline

- Onboard Photovoltaic (PV) Systems for EV/HEV
- Luminescent Solar Concentrator (LSC) Device and LSC-Enhanced PV Cells
- LSC-Enhanced Reconfigurable Onboard PV System for EV/HEV
- Reconfiguration Algorithm Acceleration
- Experimental Results
- Conclusion

Conclusion

- We propose to adopt the semiconductor nanomaterial-based luminescent solar concentrator (LSC)-enhanced PV cells in the onboard PV systems.
  - In the system design stage, we group LSC-enhanced PV cells into macrocells, and reconfigure the onboard PV system based on macrocells.
  - We simplify the partial shading scenario by assuming an LSC-enhanced PV cell is either lighted or completely shaded.
  - We make use of the observation that the conversion efficiency of the charger is high and nearly constant as long as its input voltage exceeds a threshold value.
  - We test and evaluate the effectiveness of the proposed algorithms in the two scenarios by comparing with the optimal PV array reconfiguration algorithm and simulating an LSC-enhanced reconfigurable onboard PV system using actually measured solar irradiance traces during vehicle driving.
- Experiments demonstrate the output power of algorithm 1 is 9.0% lower in average than that of the optimal PV array reconfiguration algorithm and thus algorithm 3 (Scenario 1) may not be suitable for being employed for PV systems on EVs/HEVs. The proposed algorithm 4 (Scenario 2) has 1.16X performance improvement for LSC-enhanced reconfigurable onboard PV system.

Thank You!

Questions?