A DYNAMIC RECONFIGURATION TECHNIQUE FOR PV AND CAPACITOR ARRAYS TO IMPROVE THE EFFICIENCY IN ENERGY HARVESTING EMBEDDED SYSTEMS

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Abstract: It is important to maintain high efficiency when using an energy generation source. This high efficiency can be obtained by a high generating efficiency or a high transferring efficiency. Conventional maximum power point tracking (MPPT) techniques do not consider the transferring efficiency in the multiple load system. This paper presents a generalized technique for dynamic reconfiguration of a PV/supercapacitor array with considering the power consumptions in multiple loads. This technique will minimize the power loss in the converter and charger of the system. The experimental results show that there is 20-70% power loss reduction comparing with the conventional MPPT technique in our proposed system. This will make the system more reliable to operate in stand-alone situation.

1 INTRODUCTION

The global demand for electric energy has continuously increased over the last few decades, and the energy price continuously goes up. The recent increase in oil and gas prices has prompted everyone to take a care for the energy supply and demand. Another important consideration is the fossil fuel greenhouse gases, which affect the climate changes. In order to meet the increasing energy demand in the near future, we will be forced to seek environmentally clean and renewable energy sources. This is the reason that an energy harvesting from the environment has been evolving very rapidly.

Energy harvesting itself is not new, however what makes it new is how to build efficient energy harvesting capabilities into the system. This high efficient energy harvesting can be classified into a high generating efficiency and a high transferring efficiency. We can say that a system has higher generating efficiency when it generates more power than the others in a same situation. We can say that a system has higher transferring efficiency when it has a lower power loss than the others to transfer the generated energy to consumer.

In this paper, we proposed a technique to improve the transferring efficiency in a system with photovoltaic (PV) cells. This system contains supercapacitors to compensate the output power variation of the PV cells. Supercapacitors are one of the promising energy storage elements for the energy harvesting system because of the long cycle lifetime ant the low negative environmental impact. Although we demonstrate our proposed method on a system with PV cells and supercapacitors, the proposed method is not limited to them.

2 RELATED WORK

The output characteristics of a PV array vary nonlinearly when temperature or irradiance conditions change. Therefore, the maximum power point tracking (MPPT) techniques are exploited for adjusting the operating point of the PV cells. IV and PV characteristics for a commercially available PV array is shown in Figure 1. The curves of the PV array are obtained from datasheets (Towada Solar Co. LTD., 2012). The PV array consists of 10 basic PV cells connected in series. The maximum power point (MPP) of the PV array is at a point of (5.08V, 81.8mA) for given insolation and temperature conditions. The MPPT technique first identifies the maximum power point (MPP) to draw the maximum power of PV and continuously

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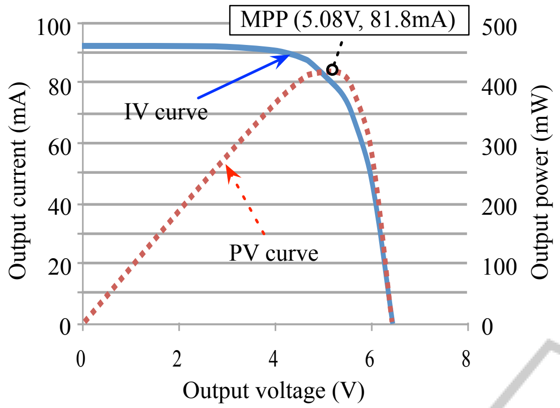


Figure 1: Maximum power point of PV cell (10 series connection module, (Towada Solar Co. LTD., 2012)).

keeps track of this point against the irradiance variation and/or load impedance variation. There are many previous methods that achieve MPPT.

The methods including a perturb-and-observe (P&O) method, an incremental conductance technique (Hohm and Ropp, 2000), a ripple correlation control method (Esram. et al., 2006) and a linear model based method (Brunelli et al., 2009) (Simjee and Chou, 2006) have been proposed. The P&O method and incremental conduction method identify the MPP by generating a slight change in the current of PV and observing the change in the power of PV. Ripple correlation control method finds the MPP using the time derivative of the current of PV and the power of PV. As for economical implementations of MPPT, a small pilot cell or a linear relationship of the MPP to the open-circuit voltage or short-circuit current can help estimate the MPP.

All these MPPT techniques are mainly focused on the energy generation side. As an aspect of the energy transferring side, the energy efficiency of switching converters and voltage regulators has received some attention, like battery-aware power management (Rong and Pedram, 2002), and switching converter efficiency- aware power management (Choi et al., 2007). A power matching scheme in (Braunstein, 1981) suggests a reconfigurable PV cells to minimize the power loss in DC-DC converter. Recently, a maximum power transfer tracking (MPTT) technique is proposed (Kim et al., 2010). The key point of the MPTT technique is that it guarantees the maximum energy is transferred into the energy storage element though a charger.

There were some more activities to reduce the output voltage range of a supercapacitor array by a series-parallel reconfiguration technique in (Uno, 2009) and to maximize a cycle efficiency and utilization of the supercapacitor array by reconfiguring the series-parallel connection in (Kim et al., 2011).

All these previous techniques are very effective to make an efficient harvesting system. However, it may not be true for a system with multiple supply voltage loads. We will briefly show this in the next Section.

3 MOTIVATION

3.1 The Power Loss in DC-DC Converters

The DC-DC conversion has been an integral part of the power delivery chain in energy harvesting systems because the conventionally targeted synchronous computation load demands stable supply voltage, which cannot in general be supplied by power harvesters directly.

The first motivation of this work comes from the fact that the power loss in a DC-DC converter depends on the difference between its input and output voltages. More specifically, larger voltage difference between the input and the output voltages results in a larger power loss in the DC-DC converter in general. For example, if the power source supplies a much higher voltage than the supply voltage of a target electric system, a DC-DC converter is typically used between the PV array and the electric system for the step-down conversion. However, the conversion dissipates a considerable amount of power in the DC-DC converter if the voltage difference between its input and output is large. Figure 2 shows characteristics of a recent commercial very high efficient buck-boost converter from TI (Texas Instruments, 2012). This shows that the power dissipation in the converter is 37.8mW, if the input and output voltages are 5.5V and 1.8V, and the output current is 100mA respectively. This power loss, 44.4mW is about 25% (= 44.4/180) overhead for the output power, 180mW.

3.2 Motivational Example

Suppose we have an embedded system consisting of an energy generator, several types of electronic modules, and dedicated DC-DC converters as shown in Figure 3. As mentioned above, the power loss in a DC-DC converter is roughly proportional to the difference between the input and output voltages. According to a commercial buck-boost converter (Texas Instruments, 2012), 44.4mW is dissipated in the converter if the input and output voltages are 5.5V and 1.8V when the output current is 100mA. In this case, 25% (= 44.4/180) of the load power consumption is

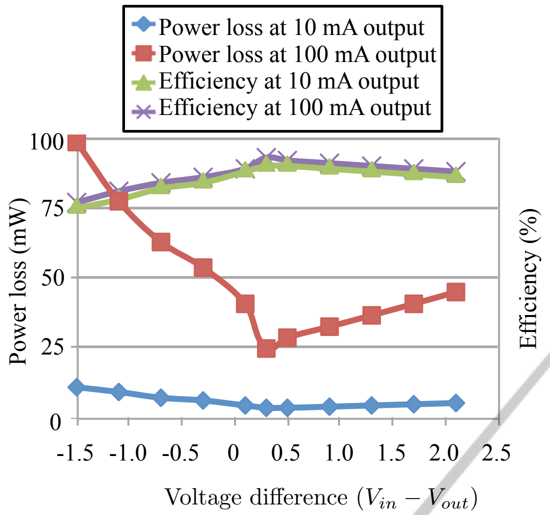


Figure 2: The efficiency and power loss of buck-boost dc-dc converter when the output voltage is 3.3V (Texas Instruments, 2012).

dissipated in the converter since supply voltage and current of a load are assumed to be 1.8V and 100mA, respectively in this example.

If we can change the output voltage of the energy generator somehow into 2.1V, the power loss in the converter can be reduced from 44.4mW to 13.5mW. This is more than 13.7% (= (44.4-13.5)/(44.4+180)) reduction in the total power consumption.

Now we assume that the energy generator is a PV cells array. A single PV cell is assumed to follow the MPP to maximize the power generation in this paper. This is because the decreasing power slope in a PV cell is generally much deeper than the increasing efficiency slope in a DC-DC converter. This means that following MPP always results in the maximum power generation. According to Figure 1, the output voltage of the single PV cell is roughly 0.5V. Therefore, we can make 2.0V by connecting each cell in series or parallel connection. The $m \times n$ configuration is shown in Figure 4. This is one of the key ideas in (Braunstein, 1981).

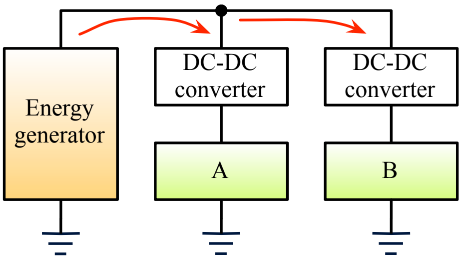


Figure 3: A embedded system of PV cells.

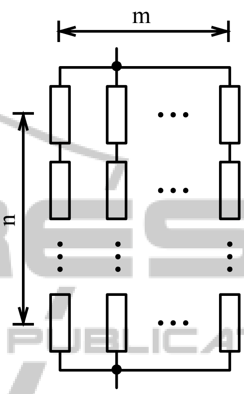


Figure 4: The (m,n) array matrix.

However, recent embedded systems contain more than one supply voltage. Figure 3 shows a typical embedded system. A and B will use different supply voltages, and the number of components will be more than one. In this system we need to consider the power consumption of each consumer component since the power loss in the DC-DC converter strongly depends on its output current. More specifically, a higher output current results in a larger power loss in the converter. Therefore, if there are multiple loads which use different supply voltages in a target system as shown in Figure 3, the total power loss in DC-DC converters can be reduced by considering all power consuming loads. This is the key difference from the previous work.

For example, if A using a 1.8V voltage supply consumes 100mA and B using a 5.0V supply consumes 1mA, the DC-DC converter dedicated for A wastes 39.9mW and that for B dissipates 0.6mW when the output voltage of the power source is 5.08V. The total power loss in the DC-DC converters is 40.5mW in this case. However, if the output voltage of the power source is set to 2.0V, the total power loss can be reduced to 22.4mW since the converter for B dissipates only 2.3mW and the converter for A dissipates 20.2mW. This means that the power loss in the converters can be reduced by 45% (= (40.5-22.4)/40.5) by appropriately setting the output voltage of the power source. We can see that even the converter widely steps up the voltage from 2.0V to 5.0V, the effect also may be small if the current is small. On the other hand, if A and B consume 10mA and 80mA, respectively, the dedicated DC-DC converter for A dissipates only 2.0mW when the output voltage of the power source is set to 2.0V. However, the DC-DC converter of B dissipates 183.1mW for boosting up the voltage from 2.0V to 5.0V. In this case, choosing a 5.08V as the output voltage of the power source is much better solution than choosing 2.0V (only total 51.4mW dissipation in this situation).

The example described above shows that the voltage selection for the output voltage of the power

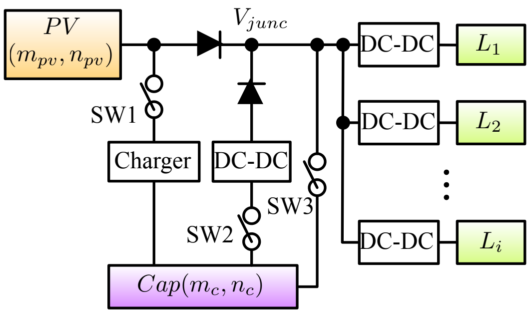


Figure 5: The proposed system blockdiagram.

source with taking the power consumptions in the loads has a strong impact on the power losses in the DC-DC converters. However, previous techniques do not consider the variety of power consumptions in multiple loads.

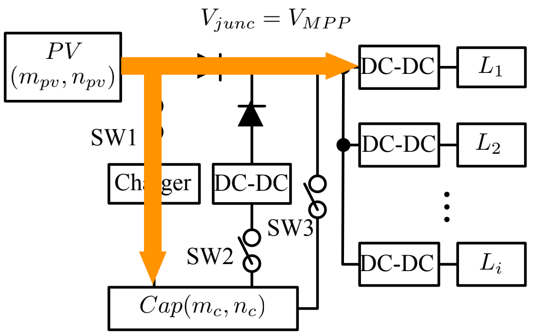
4 OUR APPROACH

4.1 Proposed System Architecture

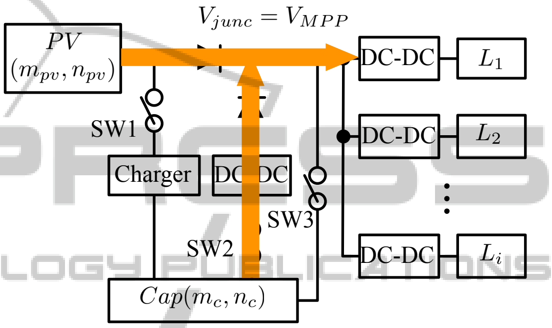
Our proposed system block diagram is presented in Figure 5. The proposed system contains a PV array, a supercapacitor array, a supercapacitor charger, a DC-DC converter for a supercapacitor array, three load components and its DC-DC converters, three switches and two diodes.

The PV/supercapacitor array has many small cells, and their series-parallel connection can be dynamically changed. The configuration (m,n) should be balanced because the size of each cell is same (Figure 4). As an example, four cells can be connected (4,1), (2,2) or (1,4) only. The number of possible configuration is the same as the number of common divisor. The number of possible configuration for four cells is three because $4 = 2^2$ $(2+1 = 3)$. As another example, twelve cells can make six configurations ($12 = 2^2 \times 3$ this means $(2+1)\times(1+1) = 6$). This configuration is controlled by switches, and dynamic reconfiguration is possible at the running time.

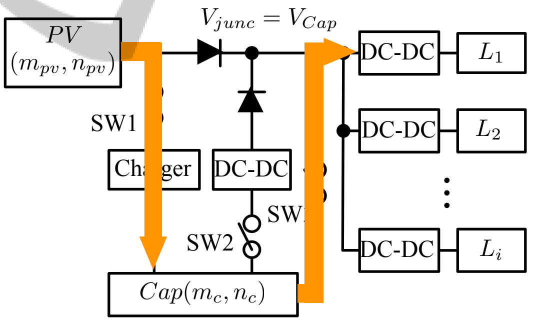
Each load component has a different supply voltage and a different power consumption. The output of a PV array and a supercapacitor array has wide range because of the configuration or the environment. To make adjustable, all DC-DC converter is buck-boost type converter. If a L_i (i-th load) requires a supply voltage of V_{L_i}, a $Conv_i$ (a DC-DC converter of L_i) will generate V_{L_i}. It is similar to the $Char_{cap}$ (supercapacitor charger) and the $Conv_{cap}$ (supercapacitor DC-DC converter).



(a) Good harvest mode



(b) Hybrid mode



(c) Bad harvest mode

Figure 6: The operating mode in the proposed system.

The purpose of the diode is implementing a multi-source power system in case that the output power of PV array is not enough for the consumer components. We can maintain MPP in the PV array by setting the output voltage of $Conv_{cap}$ to the voltage of MPP. However, the power dissipation in the normal diode demands lots of power due to its forward voltage drop. Even though it is a Schottky diode, it has 0.5V forward voltage drop. As a solution for this problem, we use an ideal diode from Linear Technology (Linear Technology, 2012) in our proposed design.

The system operation is changed in three modes by the sunlight strength and the power consumption behavior. If the sunlight is enough to generate the power consumption of the loads, the remaining power is needed to charge to the supercapacitor. In this case SW1 is turned on, and SW2 and SW3 are turned off (Figure 6(a)). The amount of charging current is controlled by an energy management system (EMS) to keep the PV array in MPP, and so the input voltage of the load DC-DC converters is V_{MPP}. EMS should monitor the status of system components in all the time. This is the first operating mode; *good harvest mode*. The second mode; *hybrid mode* is that the sunlight is not enough to cover the power consumption of the loads. In this case SW1 and SW3 are turned off, and SW2 is turned on (Figure 6(b)). The output voltage of the $Conv_{cap}$ is set to the voltage of MPP to keep the PV array in MPP, and so the input voltage of the load DC-DC converters follows V_{MPP}. The power is supplied by the PV array and the supercapacitor array at the same time. Only the necessary amount of power will be automatically supplied from the supercapacitor array because of the diode and the output voltage of $Conv_{cap}$. The last third mode is *bad harvest mode*. If the sunlight is very low, the power loss in the $Conv_{cap}$ may be more than the amount of generated power from the PV array. In this case, EMS turns on SW1 and SW3, and it turns off SW2 (Figure 6(c)). The output voltage of the PV array is V_{MPP} to maximize the generated power, and the input voltage of the load DC-DC converter is V_{cap}. The power is directly supplied by the supercapacitor array without a DC-DC converter.

4.2 Component Modeling

We assume that there is no power loss in switch and diode. Also, we assume that there is no characteristic changing when the PV or supercapacitor array configuration is changed. As an example, if we make a (m,n) connection of PV cells, the output voltage will be n times of the single cell output voltage, and the output current will be m times of the single cell current. Similarly, a (m,n) connection of supercapacitors will be n times of the single supercapacitor output voltage with m/n times of the single supercapacitor capacity.

A power converter is to deliver regulated voltage or current at a desired level regardless of a variation in the input power source and/or the load device. The efficiency of a common buck converter or boost converter is related by i) output current, ii) input voltage and iii) output voltage. However, recent high efficient buck-boost converter such as TPS63030 (Texas Instruments, 2012) from TI changes its operation mode by an operation situation. As a result, this converter will maintain almost same efficiency at the range of 1 to 100 mA output current, and its efficiency is almost only affected by the input and output voltage difference. In this paper, we assume that all the converter efficiency (including supercapacitor charger) can be achieve by the following equation. This equation is estimated from the datasheet of TPS63030.

$$\begin{aligned} 1 \leqq V_{in} \leqq 7.5 \\ 0 \leqq V_{out} \leqq 7.5 \\ x = V_{in} - V_{out} \end{aligned}$$

$$\eta_{converter}(V_{in}, V_{out}) = \begin{cases} 0.213x^3 + 1.34x^2 + 9.23x + 89.2 & : \; x < 0.3 \\ -2.67x + 93.5 & : \; x \geqq 0.3 \end{cases} \tag{1}$$

The buck mode and boost mode is changed by 0.3V difference. If the voltage difference is smaller than 0.3V, the converter operates in boost mode, and the converter operates in buck mode in the other case.

4.3 The Proposed Algorithm

The power loss in a converter is defined by

$$P_{loss} = P_{in} - P_{out}. \tag{2}$$

Also, the converter efficiency is

$$\eta = \frac{P_{out}}{P_{in}}. \tag{3}$$

From the equation (2) and (3) the power loss in a converter can be expressed by

$$\begin{aligned} P_{loss} &= P_{out} \times \left(\frac{1}{\eta} - 1\right) & (4) \\ &= P_{in} \times (1 - \eta). & (5) \end{aligned}$$

The pseudocode of the proposed algorithm is presented in Figure 7. The proposed algorithm does not decide the operating point of the PV array. However the voltage point is decided by MPPT algorithm. The amount of charging current to the supercapacitor array is also decided by MPPT algorithm. This MPPT algorithm can be any technique such as perturb and observe, incremental conduction, etc. The proposed algorithm will be used in EMS, which monitors the entire system. The output of the proposed algorithm is the configuration of the PV/supercapacitor array and the switch control.

We first calculate the power consumption of the loads including the power loss of its DC-DC converters (line 5). If the sunlight is enough to charge, we will consider it as *good harvest mode* that will make the system to charge energy to the supercapacitor array (line 6-12). If the generated power is not enough, we should decide the operation mode between *hybrid*

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Input:  $V_{MPPT}$: optimal voltage decided by MPPT
        $S_{cap}$: SoC of single supercapacitor
        $P(L_i)$: power consumption in $L_i$ component
Output: $m_c$, $n_c$: supercapacitor array configuration
        $m_{pv}$, $n_{pv}$: PV array configuration
        $SW$: SW1, SW2 and SW3 system switch on/off
1.  $SW \leftarrow (1,0,0)$
2.  $P_{pv} \leftarrow$ PV generating power by MPPT
3.  $P_{loss} \leftarrow \infty$
4.  for each configuration of PV and supercapacitor array
5.    $P_{load} \leftarrow \sum(P_{L_i} \times (1/\eta_{L_i}))$
6.    if $P_{pv} \geqq P_{load}$ then
7.      $P_{temp} \leftarrow P_{load} + (P_{pv} - P_{load})(1 - \eta_{charger})$
8.      if $P_{loss} > P_{temp}$ then
9.        $P_{loss} \leftarrow P_{temp}$
10.       $SW \leftarrow (1,0,0)$
11.       $(m_c, n_c, m_{pv}, n_{pv})$ $\leftarrow$current configuration
12.     end if
13.   else then
14.     $P_{caploss} \leftarrow (P_{load} - P_{pv})(1/\eta_{Conv_{cap}} - 1)$
15.     if $P_{pv} > P_{caploss}$ then
16.       $P_{temp} \leftarrow P_{load} + (P_{load} - P_{pv})(1/\eta_{Conv_{cap}} - 1)$
17.       if $P_{loss} > P_{temp}$ then
18.         $P_{loss} \leftarrow P_{temp}$
19.         $SW \leftarrow (0,1,0)$
20.         $(m_c, n_c, m_{pv}, n_{pv})$ $\leftarrow$current configuration
21.       end if
22.     else then
23.       $P_{temp} \leftarrow P_{load} + P_{pv}(1 - \eta_{charger})$
24.       if $P_{loss} > P_{temp}$ then
25.         $P_{loss} \leftarrow P_{temp}$
26.         $SW \leftarrow (1,0,1)$
27.         $(m_c, n_c, m_{pv}, n_{pv})$ $\leftarrow$current configuration
28.       end if
29.     end if
30.   end if
31. end for
32. Return $(m_c, n_c, m_{pv}, n_{pv})$ and $SW$.
```

Figure 7: Pseudocode of the configuration algorithm.

mode and *bad harvest mode*. The power loss in the $Conv_{cap}$ may be more than the amount of generated power from the PV array, and it will be better to supply directly by the supercapacitor array without the power loss in the $Conv_{cap}$. To decide the operation mode, we first assume *hybrid mode*, and we calculate the power loss in the $Conv_{cap}$ (line 14). If the power loss in the $Conv_{cap}$ is smaller than the generated power from the PV array, the system will operate in *hybrid mode* (line 15-21). If it is larger than the generated power, the system will operate in *bad harvest mode* (line 22-28). We will compare the total power loss in all the possible configuration cases, and then decide the optimal setting for the PV/supercapacitor array and the control of switches.

5 EXPERIMENTS AND RESULTS

5.1 Experimental Setup

We use three electronic components as a load. A CPU operates in 1.2V with 100mA consumption, a memory operates in 3.3V with 30mA consumption and a RF amplifier for WCDMA operates in 5V with 100mA consumption. The PV array is composed with twelve cells, and the supercapacitor array has six 1F supercapacitors. The number of possible configuration is 24 because the PV array has 6 possible configurations, and the supercapacitor array has 4 possible configurations, as we already present the counting method in Section 4.1. One PV cell generates 41mW (81.8mA, 0.5V) in 100% sunlight strength.

We use two systems as a baseline. One is a MPPT system with a 490.8mW PV array (81.8mA, 6V, same as a PV(1,12) array) and a 2 series connection with 6F capacitor (same as a C(3,2) array). This MPPT system will not change the PV/supercapacitor array configuration, and the output voltage of single PV cell is the same as that of the proposed system. The other is a MPTT system with the same PV/supercapacitor array of the MPPT system. This means the MPPT and MPTT system will maintain the (3,2,1,12) configuration all the time. The MPTT system is targeting to reduce the power loss in the supercapacitor charger only because it does not consider the power loss at the load DC-DC converter. One different thing from the proposed system and the MPPT system is that the PV array operation point in the MPTT system will be changed to maximize P_{charge}. The generated power (P_{pv}) will be decreased by changing the operating point. However the supercapacitor charger efficiency may increase in the MPTT system.

We will show the result of 10 selected cases, which are shown in Table 1. Each case contains the power consumption of the load, sunlight strength and a state-of-charge (SoC) of the supercapacitor. We do not include 0% sunlight strength case because MPPT and MPTT can optimize nothing in this case.

5.2 Results

First, we show an accumulated bar by the power loss of each converter in Figure 8. We can see that (2,3,2,6) configuration has the lowest power loss among the cases. There is a configuration that has the lowest power loss in one converter, yet it is not mean that the total power loss is the lowest. The total power loss may be the lowest, even though a power loss in one converter is larger than the other configuration. This means we should consider the power loss in the

Table 1: Selected cases for the experimental result.

No.	Current (mA)			Sun (%)	S_{cap} (%)
	CPU	Mem.	RF Amp.		
Case 1	1	1	1	100	20
Case 2	1	1	1	100	40
Case 3	1	1	1	100	60
Case 4	1	1	1	100	80
Case 5	100	30	1	50	20
Case 6	100	30	1	50	80
Case 7	100	30	1	100	40
Case 8	1	30	100	50	20
Case 9	1	30	100	50	40
Case 10	1	30	100	50	80

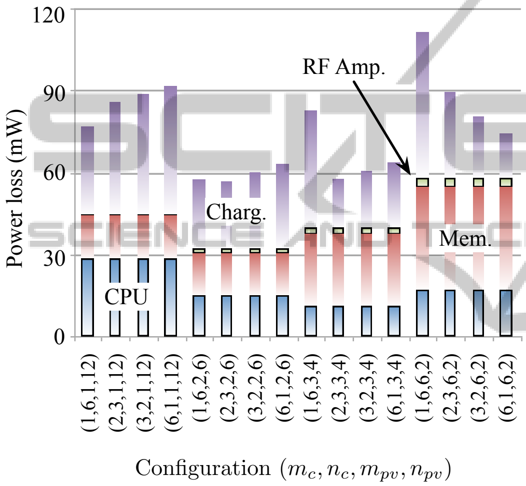

Figure 8: The power loss in each converter in one case by the configuration (CPU, Mem. and RF amplifier module consume 100, 30, 1 mA. Sun 100% and S_{cap} =20%.

system all together.

Table 2 shows the result of the selected cases. The alphabet in Oper. mode column shows the operation mode; G: *good harvest mode*, H: *hybrid mode* and B: *bad harvest mode*. The Red. means the reduction ratio, and it is calculated by the following equation

$$Red.(system) = \frac{P_{loss}(MPPT) - P_{loss}(system)}{P_{loss}(MPPT)}. \quad (6)$$

In all cases, the MPTT cannot achieve more than 1% reduction comparing the MPPT system. Therefore, we just show one case result for the MPTT. This is because we assume i) small size of PV cell and ii) a high efficiency in the supercapacitor charger. A small size of PV cell and a high efficiency charger will make hard to move the operating point in the PV array. Even If the operating point is slightly changed, the generating power from PV array will highly decrease. At the same time the efficiency of charger is not changed much to compensate the decreasing amount of generated power. Therefore, the MPTT is almost same as the MPPT in our design.

We can see that the operation mode is changed by the load profile, a supercapacitor SoC or sunlight strength changing. Case 5 and Case 8 show the situation of load profile changing, and Case 7 and Case 9 show the situation of sunlight strength changing. Case 8, Case 9 and Case 10 clearly show the situation of direct discharging from the supercapacitor array. Although there is sunlight, we cannot use the generated power directly by a system situation to maintain MPP. The generated power from the PV array should be charged to the supercapacitor array, and the load component should be directly supplied by the supercapacitor array. This reduces the total power loss in this case.

6 CONCLUSIONS

This paper presents a generalized technique for optimizing the series-parallel connections of PV array and supercapacitor array with considering the power consumptions in multiple loads which use different supply voltages as well as the power dissipated in the corresponding DC-DC converters. The output of the proposed algorithm is the control of the power path switch and the configuration of the PV/supercapacitor array in the proposed system. The configuration of PV array should be dynamically changed when the system status is changed. The supercapacitor array can be a source or load in the system by supercapacitor converter and charger. This means even in the same operating condition, the configuration of PV arrays and supercapacitor array need to be changed by the SoC of supercapacitor.

While conventional MPPT maximizes the solar cell output power without considering the power loss in the DC-DC converter and charger when there are multiple loads, we consider the power loss and introduce a dynamic reconfiguration of PV arrays and supercapacitor arrays. Also, our proposed technique can be used with any kind of MPPT techniques.

Our proposed technique will increase the reliability of the system without increasing a PV array or an energy storage. The proposed technique increases the transferring efficiency by minimizing the total power loss in the converters.

ACKNOWLEDGEMENTS

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Table 2: Selected experimental results.

Case	Configuration ($(m_c, n_c, m_{pv}, n_{pv})$)	Oper. mode	Converter power loss (mW)						Red. (%)
			CPU	Mem.	RF Amp.	Charg.	$Conv_{cap}$	Total	
Case 1	MPPT	G	0.3	0.5	0.5	95.3	-	96.6	-
	MPTT		0.3	0.5	0.5	95.0	-	96.3	0
	Proposed (2,3,3,4)		0.1	0.9	2.4	37.4	-	40.8	58
Case 2	MPPT	G	0.3	0.5	0.5	82.5	-	83.8	-
	Proposed (3,2,2,6)		0.2	0.5	1.7	43.9	-	46.3	45
Case 3	MPPT	G	0.3	0.5	0.5	69.6	-	71.0	-
	Proposed (6,1,3,4)		0.1	0.9	2.4	37.4	-	40.8	42
Case 4	MPPT	G	0.3	0.5	0.5	56.8	-	58.1	-
	Proposed (6,1,2,6)		0.2	0.5	1.7	43.9	-	46.3	20
Case 5	MPPT	H	28.7	15.7	0.5	-	29.0	74.0	-
	Proposed (1,6,2,6)		15.3	15.4	1.7	-	2.0	34.4	54
Case 6	MPPT	H	28.7	15.7	0.5	-	10.0	54.9	-
	Proposed (3,2,2,6)		15.3	15.4	1.7	-	1.7	34.1	38
Case 7	MPPT	H	0.3	15.7	50.5	-	116.8	183.3	-
	Proposed (1,6,1,12)		0.3	15.7	50.5	-	21.3	87.8	52
Case 8	MPPT	B	0.2	37.6	332.1	47.6	-	417.5	-
	Proposed (1,6,2,6)		0.2	15.4	172.1	25.9	-	213.5	49
Case 9	MPPT	B	0.1	26.3	237.3	41.2	-	304.9	-
	Proposed (1,6,1,12)		0.3	15.7	50.5	25.9	-	92.4	70
Case 10	MPPT	B	0.2	9.0	116.5	28.4	-	154.2	-
	Proposed (2,3,1,12)		0.3	15.7	50.5	25.9	-	92.4	40

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