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Applying Power Management and Wireless Sensing System to Plant Factory

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Abstract. *The problem of greenhouse effect is more serious day by day. This study proposes a photovoltaic (PV) system with power management technology to a plant factory. The major structures of this system include a PV energy system, power management algorithm, and plant factory. In this system, the solar power generator is the major energy supporter and the utility power will supply loads only when both battery energy and solar energy are insufficient. The system model is controlled by a central management unit which chooses a suitable model based on the environment conditions. For the plant factory, a wireless sensing system is applied to monitor the environment situations and supply the environment information which includes temperature, humidity and illumination to users via the computer network. Users can adjust the environment conditions to enhance the plant growth.*
Keywords: Greenhouse effect, Power management technology, Wireless sensing system.

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1. **Introduction.** Because the development of industry and economic growth rapidly, the demand of energy is increased significantly in recent years. Moreover, large amounts of factories and automobiles produce too much CO_2. The concentration of CO_2 in atmosphere is increased, which will enhance the greenhouse effect on the earth and cause the global climate changed. Therefore, the renewable energy is paid more attention in many countries today. In this paper, a power management and micro bubble technologies are applied to a plant factory. In order to monitor the plant factory, a wireless sensing system is applied to adjust the environment conditions to enhance the plant growth.

In the research, one plant factory is developed for soilless cultivation and its power is provided by multiple power sources which include photovoltaic (PV) system [1-3], batteries, and utility power. However, the PV panels can only generate electricity during day time and it needs batteries to storage electricity energy for night time. Sometimes if the power of battery is insufficient the utility power is necessary also. In this paper, one power management system is developed. In the design, solar energy, batteries, and utility power are used as input power sources to supply different loads. This research uses a transformer combined with single chip controller to control the input activation and output loads. The basic concept of this power management system [4-6] is that the solar energy is the primary source and batteries are the backup source. If both the battery and solar energy are insufficient the system switches the utility power to supply loads, and let the battery be charged through utility power at the same time.

For the plant factory, LED light is used to enhance the plant growth, the electrical conductivity (EC) and PH values of solution are under controlled also. The wireless sensing system using ZigBee sensor is applied to monitor the lightness, temperature, and humidity. The information is detected by sensors and transmitted them to the receiving device by wireless transmission. The system accesses this information to control functions and adjusts the environment factors. Based on the experimental results, the proposed system can enhance the growth of the plants effectively.

2. **Power management system.** A power management [7-8] and wireless sensing system is developed in this research. It applies multiple power sources which include solar energy, battery, and utility power to a plant factory for soilless cultivation. In this design, solar energy, batteries, and utility power are used as input power sources to supply different loads. This system uses a transformer combined with single chip controller to control the input activation and output loads. The basic circuit design structure of the typical power management system is shown in Figure 1. In usual situation of day time, the solar energy is used as the primary source and if solar energy has extra energy after supplying loads, which will be used to charge the batteries. However, if the solar energy is not enough or in night time the reserved energy in batteries will be used to supply the loads. If both the battery and solar energy are insufficient, the system model is switched to the utility power for supplying loads, and let the battery be charged through utility power also.

In this system, we use a single chip which includes two PWM signals to control the duty periods of the PV panel, grid power, and the battery. When the PV panel generates sufficient power, all the power produced by the PV panel will be used to supply loads. In this situation, the power switch S1 is turned on and current i1 is generated in the loop. According to this design, the output voltages Vload1 and Vload2 are computed as equations (1) and (2), respectively.

$$V_{load1} = \frac{N_4}{N_1} \times \frac{D}{1-D} \times V_{E1} \tag{1}$$

$$V_{load2} = \frac{N_5}{N_1} \times \frac{D}{1-D} \times V_{E1} \tag{2}$$

D is the duty cycle which is computed as $D = \frac{t_{on}}{T}$ and ton is the turn on period of power switch S_1. N_1 is the coil number of inductance of the primary coil, L_{N1}, which is computed as Eq. (3).

$$L_{N1} = \frac{V_{N1}}{i_{1pk}} \times t_{on} \tag{3}$$

The i_{ipk} is the estimated peak value of i_1 . In this design, the i_{1pk} is assumed to be three times of i_1 when the system has maximum load. The winding number N1 of the primary coil is shown as Eq. (4).

$$N_1 = \frac{V_{N1} \times t_{on}}{A_e \times B} \times 10^{\ 8} \tag{4}$$

The A_e is the effective cross-sectional area of the transformer and B is the magnetic-flux density. The inductance of the secondary coil, L_{N4}, is calculated as Eq. (5).

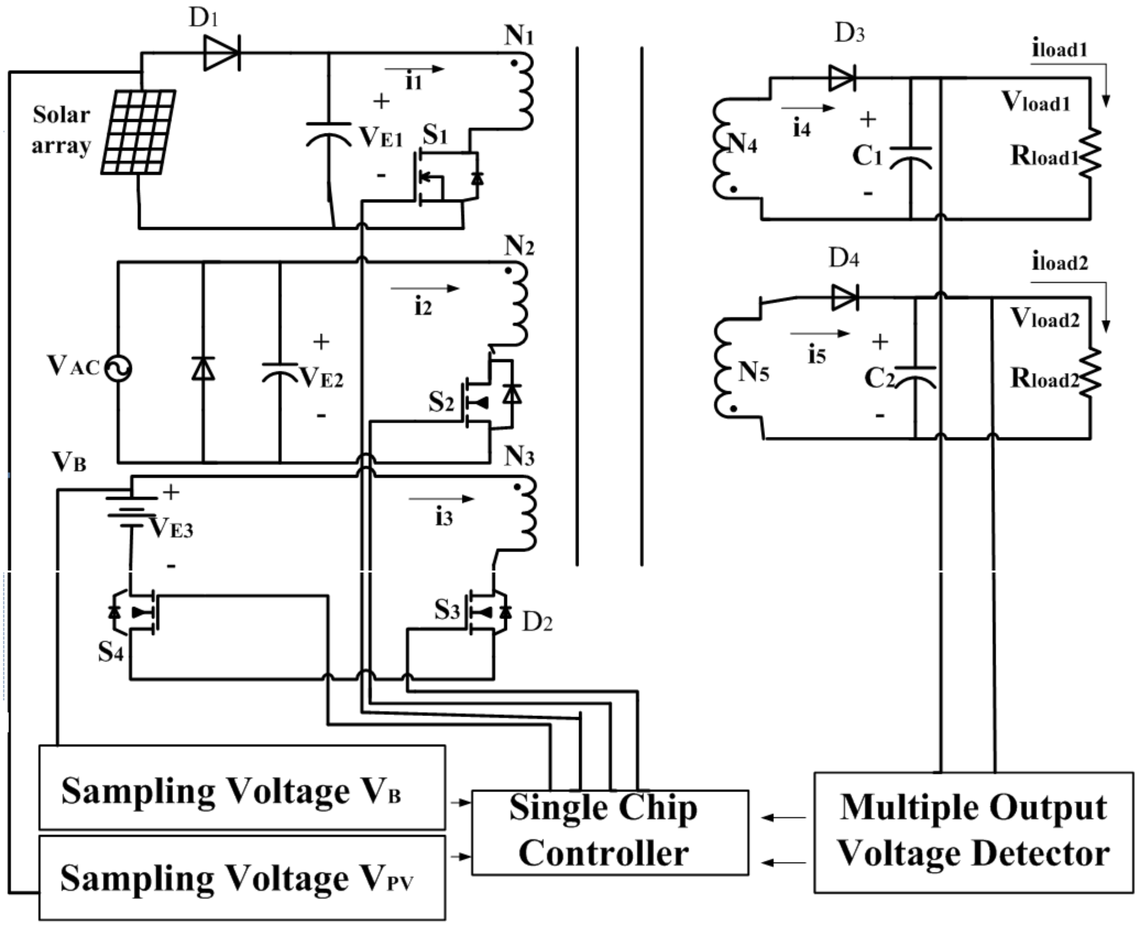

Figure 1. Typical power management system

$$L_{N4} = \frac{V_{N4}}{i_{4pk}} \times t_{off} \tag{5}$$

The winding number N_4 of the secondary coil is shown as Eq. (6).

$$N_4 = \frac{V_{N4} \times t_{off}}{A_e \times B} \times 10^{\ 8} \tag{6}$$

Another inductance of secondary coil, L_{N5}, is shown as Eq. (7).

$$L_{N5} = \frac{V_{N5}}{i_{5pk}} \times t_{off} \tag{7}$$

The winding number of the secondary coil, N5, is shown as Eq. (8).

$$N_5 = \frac{V_{N5} \times t_{off}}{A_e \times B} \times 10^{\ 8} \tag{8}$$

However, when other situations are happened the other suitable modes will be selected and it is switched by single chip. For example, when the voltages of both the PV panel and the battery are extremely low, the grid power is used to provide power to loads alone. Moreover, the battery will be charged by grid power also.

For the plant factory, the LED light is used as light sources to enhance the plant growth. The electrical conductivity (EC) and PH values of solution must be controlled for soilless cultivation. In order to monitor the plant factory situations, a wireless sensing

Table 1. Plant net weight change during the experimental period

Illuminat time	No. of plant	Day 1	Day 15	Net weight change	Average net weight (g)	EC and PH values
12 hours	1	4.16	26.78	22.62	20.46	Constant
	2	3.7	22.53	18.83		
	3	3.99	23.93	19.94		
12 hours	1	3.39	17.8	14.41	16.15	Inconstant
	2	3.48	17.23	13.75		
	3	3.38	23.67	20.29		
18 hours	1	1.81	29.77	27.96	24.82	Constant
	2	2.47	30.78	28.31		
	3	2.04	20.22	18.18		
18 hours	1	1.49	32.39	30.9	23.43	Inconstant
	2	2.44	13.14	10.7		
	3	1.73	30.42	28.69		

system which uses ZigBee sensor and LabVIEW system is applied to monitor the lightness, temperature and humidity. In the solar power system which is consisted of photovoltaic (PV) panels to generate energy, and through a charge controller to control the power management based on sunshine situations. If the current of PV array is under a certain threshold value, the controller switches to discharge mode, then the electric energy will be supplied by the battery or grid power system.

The output power of a solar energy system is depended on solar irradiation and temperature conditions. In order to obtain the maximum output power, the maximum power point (MPP) tracking algorithm is applied in a solar energy system. In this paper, an improved method based on both Perturbation & Observation method (*P&O*) and three-point weight comparison method are adopted. The basic concept of the *P&O* methods, most of them adopt the algorithm to compare two points, that is, the current operating point and the subsequent perturbation point, and then observe whether the output power should move up towards the MPP within one sampling period. After that, the comparison process will be repeated periodically in every sampling. Such algorithm results in more perturbation loss around the maximum power point. The three-point weight comparison method basically observes the variation of output power as well, only it adds one extra power point than the *P&O* algorithm before a decision is made, and performs the MPP tracking when solar irradiance stabilizes so as to reduce perturbation loss. This paper combines the advantages of two tracking methods and incorporates a judgment program for switching the MPPT controller. When slope is greater than an absolute value of 1/3, it means the output power of PV module varies drastically, and the system would switch to *P&O* method for tracking. If slope is smaller than 1/3, it means the output power of PV module stabilizes, and the tracking system would switch to three-point weight comparison method.

In order to monitor the plant factory situations, a ZigBee technology is applied in this system. ZigBee is a wireless sensor to monitor and control the entire system. It monitors important environment information such as lightness, temperature and humidity. The information is detected by sensors which transmit them to the receiving terminal device through wireless transmission. This information is also can transmit to a computer and present to users. Moreover, it uses the software to access this information and to the control functions of entire system.

Table 2. Plant growth comparison with (without) micro bubble generator

	Plant No.	Day1	Day15	Net weight
With micro bubble generator	1	6.6	61	54.4
	2	5.49	63.55	58.06
	3	4.69	59.91	55.22
Without micro bubble generator	1	5.99	38.97	32.98
	2	4.91	42.9	37.99
	3	4.56	41.16	36.6

3. **Experimental Results.** In the experiment, several different situations are considered. Based on soilless cultivation, variable illumination time for the plant growth is adopted. The electrical conductivity (EC) and PH values of hydroponic solution are to maintain constant in first experiment. In second experiment, both EC and PH values are inconstant.

The entire system is monitor by ZigBee system. According to the experimental procedure described as above, the net weight change of plants after the period of fifteen days of cultivation is shown in Table 1. Based on the experimental results, the plant average net weight is heavier if the illumination time is longer. Moreover, the plant average net weight is heavier when both EC and PH values are kept constant.

In the third experiment, illumination time, electrical conductivity (EC), and PH values of hydroponic solution are maintained constant. But one micro bubble generator is used to generate micro bubble one minute every one hour during the period of growth. Because micro bubble is very light, therefore it will stay in water much longer than usually bubble. The plant has more air for its root. Based on the experimental result, the experiment with micro bubble generator has better growth situation. The result is shown in Table 2.

4. **Conclusions.** In this research, one plant factory is developed for soilless cultivation. The power management method is used to adjust energy supporting system. In order to monitor the plant factory situations, the ZigBee technology is applied to monitor the lightness, temperature, and humidity. Based on the experimental results, the plant average net weight is heavier if the illumination time is longer. Moreover, the plant average net weight is heavier when both EC and PH values are kept constant. One new experiment is conducted.

The micro bubble is used during the period of plant growth. Based on the experimental result, the plant growth is much better when it uses micro bubble generator. We convince that the system proposed in this paper can enhance the growth of the plants and reach the goal of saving energy also.

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