Sensor-less Approaches for Maximum Photovoltaic Power Tracking Control

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Abstract – MPPT (maximum power point tracking) control is very important for the practical PV (photovoltaic) systems to maintain efficient power generating conditions irrespective of the deviation in the PV array insolation or/and temperature conditions. Although a plenty of researches have been done so far, most of them are too costly because of being too dependant on expensive sensors for measuring photovoltaic power and micro-processors for achieving elaborate and complicated control strategies. From this point of view, authors have been researching on sensor-less approaches for MPPT control, and have proposed two types of new control schemes "Power Equilibrium Scheme" and "Limit Cycle Scheme". This paper summarises these two schemes with focussing on their operating principles and some results of simulation and experiments.

I. INTRODUCTION

In order to track the time varying maximum power point of the solar array depending on its operating conditions of insolation and temperature, the MPPT (maximum power point tracking) control technique plays an important role in the practical PV systems. A variety of MPPT schemes have been proposed in the literatures so far [1]-[3]. Some of them are applying fuzzy logic, neural networks and GA (genetic algorithm) techniques, etc. in order to achieve a fast response in the transient state and a stable operation in the steady state at the same time. These new approaches seem to be very useful in some special cases from a viewpoint of their control quality. However, they are too costly for most cases because they are too dependant on expensive sensors and micro-processors. Therefore, for the most of practical mass-produced PV systems, the simpler approaches have been required.

Standing on this point of view, the authors have been focussing on the simplification of the MPPT control system by utilizing steady state power balancing condition at dc link which is the inter-link stage of two power conversion stages, i.e. a boost chopper stage and a PWM inverter stage. Then, two types of new power sensor-less MPPT control schemes, referred as "Type-1: Power Equilibrium Scheme" and "Type-2: Limit Cycle Scheme" in this paper, have been proposed [4]-[8]. Fig.1 shows the block diagrams of a typical conventional MPPT system and the two types of proposed systems. The proposed two systems both utilize the sensors for dc link voltage detection and ac current detection which are indispensable for the inverter system itself, and need no additional sensors for PV array power detection.

This paper summarizes the basic principles of these new sensor-less approaches proposed by the authors and

validates the availability of the systems by showing some simulation and experimental results.

II. TYPE-1/POWER EQUILIBRIUM SCHEME

A) Basic Operation principles

Fig.2 shows the system configuration of Type-1. For the typical conventional MPPT control schemes, it is essential to use the information of actual output power of the PV array, and the duty ratio for boost chopper is selected to maximize the output power by MPPT algorithm. On the other hand, this system need not depend on the information of actual power. In the steady state condition, the generated power of the solar array and the regenerative power flow toward the ac system should have a balance. Therefore, the
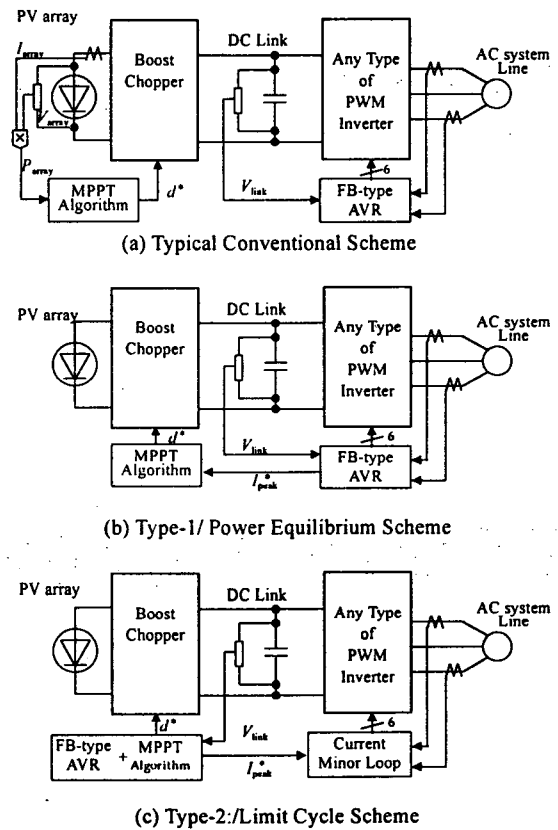

(a) Typical Conventional Scheme

(b) Type-1/ Power Equilibrium Scheme

(c) Type-2:/Limit Cycle Scheme

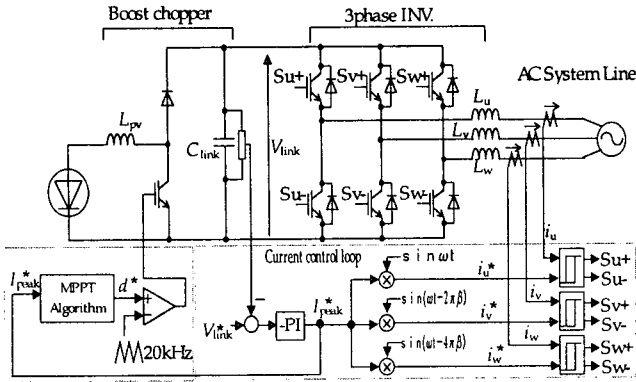Fig.1 Conventional and two types of proposed MPPT schemes.

Fig.2 System configuration of Type-1,
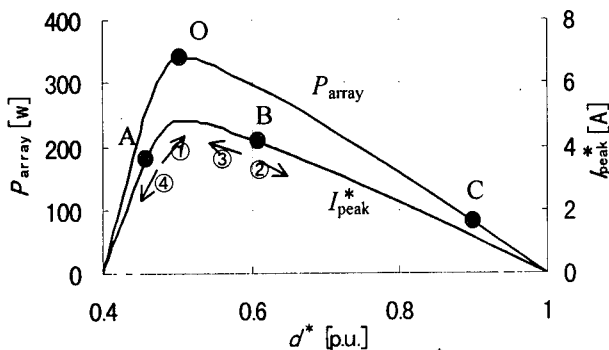"Power Equilibrium Scheme".

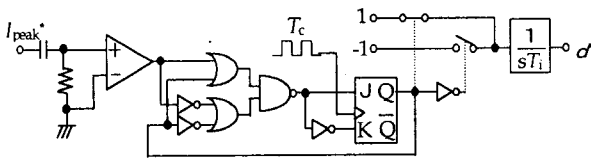Fig.3 d^* versus P_{array} and I_{peak}^* .

Fig.4 Example of a simple hardware
implementation for Type-1 MPPT control.

Table1 Operating direction of d^* in MPPT control.

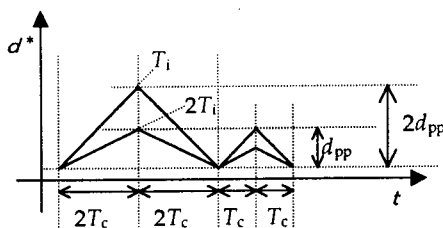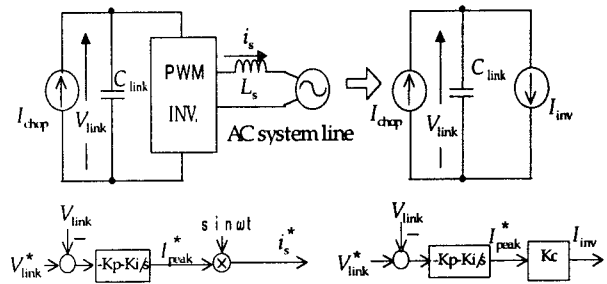| Operating Points in Fig.3	Current States		Operating
	I_{peak}^*	d^*	direction of d^*
①	Positive	Increasing	Hold on
②	Negative	Increasing	Turn over
③	Positive	Decreasing	Hold on
④	Negative	Decreasing	Turn over

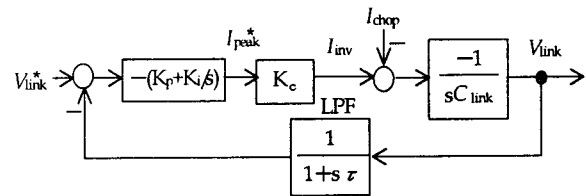Fig.5 Relations between T_i, T_c and d^*.

Fig.6 Modeling of inverter.

Fig.7 Dc link voltage control loop.

generated power Parray is in proportion to inverter output current magnitude command Ipeak* which is the inner signal of the control loop in the steady state as shown in Fig.3. Therefor, MPPT operation is achieved by maximizing Ipeak* in place of Parray.

For an easy implementation of the MPPT algorithm, a simple electronic circuit shown in Fig.4 has been examined here. Based on the differential value for the time dependent variable d(Ipeak*)/dt, the searching direction whether increasing or decreasing the value of d* is determined every sampling time Tc. That is, if Ipeak* is increasing, the searching direction is always kept constant as before irrespective of the current state of d* (Fig.3-① and Fig.3-③). On the other hand, if the differential value of Ipeak* is found to be negative at a sampling time, then the searching direction is changed irrespective of the current state of d* (Fig.3-② and Fig.3-④). This decision making is arranged in the Table 1. Fig.5 shows the relationships between the integrator time constant Ti, sampling time Tc and duty ratio command d*. Ti and Tc are the design parameters which are selected later based on Fig.9.

B) System Designing Approaches

The parameters of the main circuit and the controller are determined from the practical view point to ensure well-dumped stable operation and the sufficient quick response. For this purpose, state space averaging model is deduced by neglecting the switching phenomena of chopper and inverter stages as shown in Fig.6. Then the block diagram representation in Fig.7 can be derived. Where, the time delay τ of a first order LPF(low-pass filter) represents the equivalent total time delay of the control loop. In the case of $\tau = 0$, the system becomes a two-order system. Assuming that the two poles are assigned at a same place - α, where α is a positive real value, the equivalent time-lag
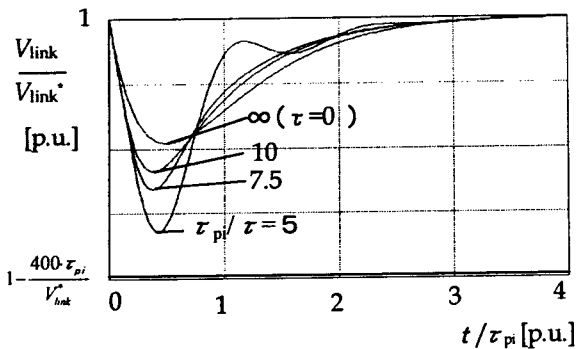
τ_{pi} of the

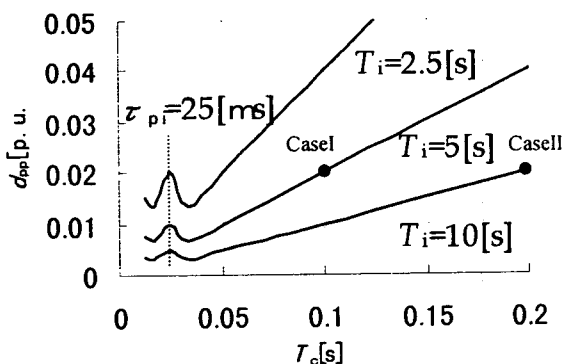
Fig.8 Step Response against disturbance.

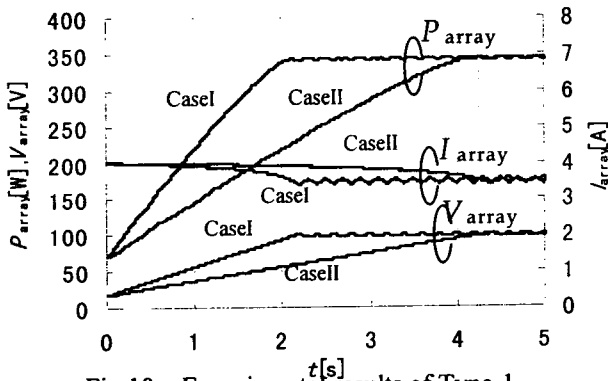Fig.9 Relationships between T_c and d_{pp}.

Fig.10 Experimental results of Type-1.

PI control loop becomes $2/\alpha$. In the real system, the time constant τ is given at first. Fig.8 shows an effect of τ on the step response waveform against disturbance. It is clear that τ_{pi} should be selected at least 5 times grater than given τ. The larger PI control gains enable the faster response, but the dumping become worse. For this reason, it is an important criterion to give the upper limit of the PI gains and ensure well dumped operation of the system.

Once the τ_{pi} is determined, the time constant Ti and Tc are selected to suppress the peak to peak value of duty ratio dpp based on the relationships shown in Fig.9. Here, two

cases I and II are selected as examples.

C) Experimental Results

In the experiment, a solar array simulator (Hewlett Packard E4351B) has been used to realize reproducible time varying insolation conditions of the PV array. A set of different v-p curves corresponding to the changing insolation conditions have been programmed.

Fig.10 shows examples of step responses for cases, A and B. They successfully track the maximum power point. The response time have been proved fast enough for the practical use.

III. TYPE-2/LIMIT CYCLE SCHEME

A) Basic Operation principles

Fig.11 shows the system configuration of Type-2. This approach is characterized by its complete removal of the conventional "mountain climbing algorithm" to optimize the operating point. As a result, the control circuit becomes extremely simple, and it is suited for very low-cost small-sized systems such as ac modules, and the pumping motor systems combined with PV arrays.

The basic operation principles are explained by using Fig.11 and the operating waveforms in Fig.12 . In this system, the dc link voltage between two power conversion stages is kept constant by the PI control loop on the left hand chopper side. At the same time, the link voltage error signal is also observed by the comparator in the load leveling loop
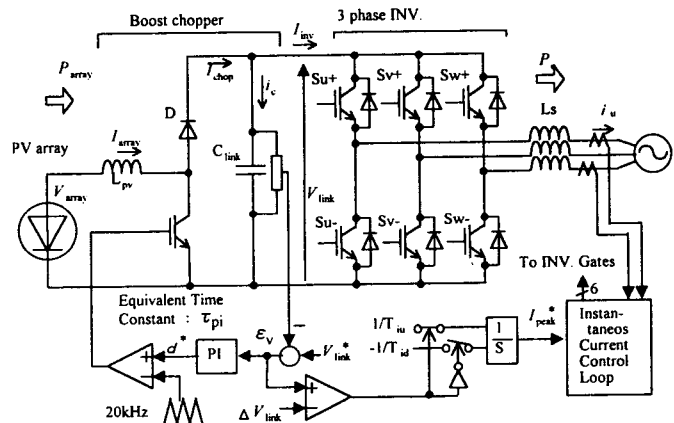

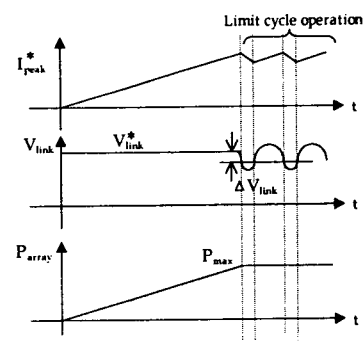Fig.11 System configuration of Type-2 "Limit Cycle Scheme".

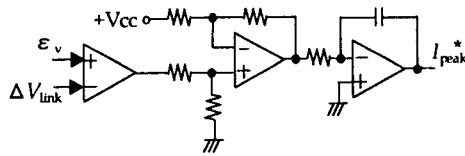Fig.12 Principle of MPPT operation utilizing limit cycle.

Fig.13 Example of a simple hardware
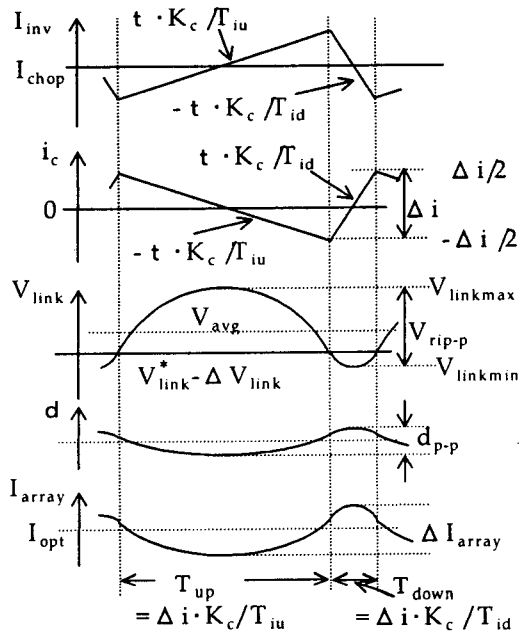implementation for Type-2 MPPT control.

Fig.14 Approximate waveforms during
limit cycle operation.

on right hand inverter side. The loading level against the PV array is adjusted by changing the ac current amplitude command Ipeak*. This system realizes such an operation simply by switching the input terminal of the integrator with two different values, +1/Tiu and -1/Tid, based on the result of error signal comparison.

Assuming the switch is connected to the positive side +1/Tiu at first, Ipeak* may start to rise up gradually as shown in Fig.12. Unless the output power Parray reaches to the maximum power point Pmax of the array, the dc link voltage Vlink may be kept constant with the help of PI control loop on chopper side. However, once Parray has reached to Pmax, Vlink could no longer kept constant because the power equilibrium cannot maintained. Thus, Vlink begins to go down, and the voltage error signal may soon become larger than a preset small value ΔVlink. Then, the switch is turned over to the negative side -1/Tid, and the Ipeak* begins to decrease. Then, Vlink gradually stops decreasing and again begins to increase. In this way, a kind of non-linear oscillation, so-called "limit cycle", occurs on the equilibrium/non-equilibrium boundary of the system

power flow around the maximum power operating point. And the generated output power on ac system side can be automatically maximized without using any information of voltage and/or current on PV array side.

Fig.13 shows an example of a simple hardware implementation for this control scheme.

B) System Designing Approaches

In order to ensure the stable operation, i.e. to guarantee the occurrence of the limit cycle, it is an important design criterion to give an adequate relationships between the time constants Tiu, Tid and the equivalent time-lag of the PI control loop, τ_{pi}. That is, the relationship, Tid > τ_{pi} > Tiu, should hold.

Fig.14 shows approximate wave forms of limit cycle operation based on a state space averaging model ignoring the high frequency switching phenomena. Basing on these waveforms, the relation between the system parameters and the resulted limit cycle frequency, amplitude of the limit cycle ripple component can be derived.

According to the latest detailed investigations [6], the limit cycle frequency does not depend on the insolation conditions. But the equivalent time-lag of the PI control loop, τ_{pi} changes in proportion to the insolation. For this reason, Tiu should be selected smaller than the minimum value of τ_{pi} in operation, say 0.2p.u. against the maximum insolation condition. For the lower insolation than 0.2p.u., the MPPT operation using limit cycle is nolonger useful, and the operating mode can be automatically switched to "constant voltage mode" simply by giving the upper limit value for d* with an additional limitter. In this mode of operation, Vlink is maintained almost constant around the voltage command with the help of inverter side feedback loop. Therefore, the dc link voltage never been crrupted or discharged over even if the photovoltaic power decreased to be complete zero.

C) Experimental Results

Three different patterns of v-p curves, A[Vo=120[V], Isc=4[A]], B[Vo=110[V], Isc=3[A]], C[Vo=100[V], Isc=2[A]], corresponding to the changing insolation conditions have been programmed in a solar array simulator (Hewlett Packard E4351B) to realize reproducible experiment.

Fig.15 shows an experimental response waveforms when the insolation condition has gradually changed as A→B→C →B→A. A successful track to the maximum power point can be observed. Fig.16 shows the expanded experimental waveforms of limit cycle operation for condition A and C, respectively. It can be seen that the limit cycle frequency is almost same, around 3[Hz], for both conditions.

IV. CONCLUSIONS

This paper has summarized two types of new power sensor-less MPPT control schemes previously proposed by the authors, referred as "Type-1/ Power Equilibrium Scheme" and "Type-2/ Limit Cycle Scheme" in this paper. Because of the short of pages, special care has been taken to explain the basic principles of the ideas, particular problems to be solved and the stances for approaching the problems

for both new schemes without using equations. The qualitative detailed investigations have been given in the references [6]-[8].

The importance of utilizing the renewable energy system, including photovoltaic system and wind turbine generation system etc., has been attracted greately in these days. Although the total energy amount is still small, it is also important in the sense of enlightening the public people to know the benefit of energy and importance of saving it through their daily life. For this purpose, continuous effort to develop more attracting systems with lower-cost, higher-performance and multi-functions are required. Sensor-less approrches explained in this paper is one of such key aspects.
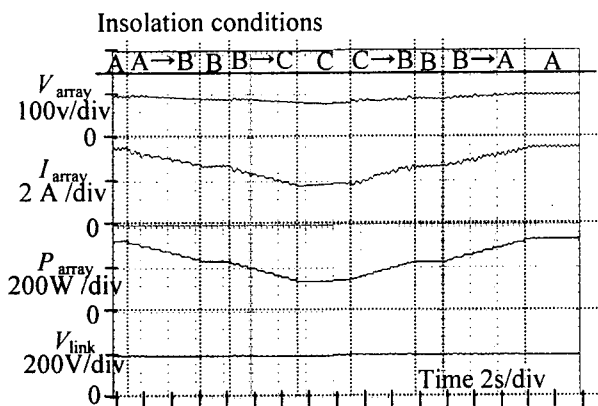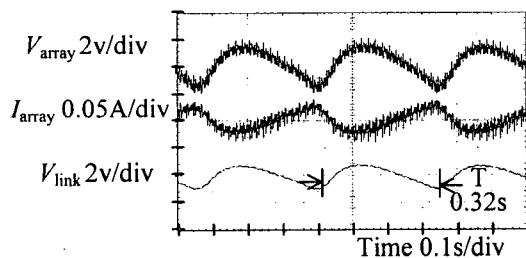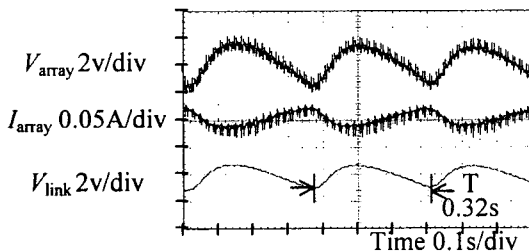

Fig.15 Experimental operating
waveforms of Type-2.

(a) Insolation condition A

(b)Insolation condition C

Fig.16 Experimental waveforms of limit cycle operation.

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