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A REVIEW ON P&O MPPT TECHNIQUES ADOPTED IN GRID CONNECTED PHOTVOLTAIC SYSTEM FOR EFFICIENT MPP TRACKING TO IMPROVE POWER QUALITY

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ABSTRACT

This paper presents an organized review on Perurb and Observe (P&O) algorithm used in grid connected photo voltaic panel for efficient tracking to improve power quality. Though there are number of algorithms in use for tracking maximum power, P&O algorithm becomes unique due to its simplicty and low implementation cost. However it suffers from two drawbacks viz. first, oscillations around MPP which genrates ripple in output voltage and second, loss of tracking direction during sudden change in insolation which causes reduction in efficiency. Many papers addresed these issues and mitigation methods have also been suggested. To review the best methods published in renowned publications, this paper has been designed to discuss in detail. This paper also discuss the importance of maximum power point tracking in grid connected PV system and explains unique difference between the methods suggested in different research articles. It is expected that by refering this article further development is possible to expand improved algorithms for tracking maximum power and there by improving power quality.

Key words: Photovoltaic (PV) panel, Maximum Power Point Tracking (MPPT), Perturb and Observe (P&O) algorithm, Adaptive Current Control (ACC), Fractional Short Circuit Current (FSCC) algorithm, Adaptive Control Algorithm (ACA).

INTRODUCTION

The increase in demand of electricity overloads distribution grid and cause power shortage. One of the methods of overcoming this problem can be integration of utility grid with solar energy system. Solar power system is getting more attention because it is plentifully available and eco friendly when compared with other power generation system. Though, manufacturing cost of PV panel is high and also it has low conversion efficiency (9%-17%), the light energy available from the sun is free and abundant which makes this system to be an economical at some extent. Moreover other non-renewable energy sources are depleting at faster rate which may not be available in future. The PV panel can perform only during sunlit days which also reduce its overall performance.

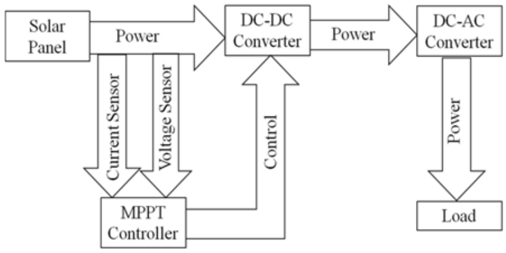

Fig.1 Grid connected PV system

To improve performance and supply power throughout the days, it is necessary to integrate with utility grid as a parallel system. The PV characteristics depend on solar insolation. The power available from PV array depends on radiation level, weather conditions and ambient temperature. The P-V curve of solar panel is non-liner in nature and has its own maximum operating point. Under varying atmospheric conditions Maximum Power Point Tracking (MPPT) is essential to obtain maximum power output from solar panel [1-4]. Many MPPT algorithms including perturb and observe (P&O) [5-7], incremental conductance [8], constant voltage [9], neural network [10], fuzzy logic [11] are in use to increase efficiency of solar panel. The MPPT algorithm modifies the phase displacement between grid and converter voltage and provide reference voltage V_{ref} to track to get maximum power. In addition, it monitors the maximum and minimum values of power on the PV side. In case of single phase grid connected photovoltaic system the instant power oscillates twice that of line frequency and these oscillations in power leads to 100Hz ripple in voltage and power on the PV side [12]. If the system operates in the area around MPP, the ripple of the power on PV side minimized and hence there will be an improvement in power quality.

Among other algorithms P&O is most popular due to its simplicity and it does not require previous knowledge of PV characteristics. It inspects dP/dV on P−V curve. he slope dP/dV is greater than zero on left side of MPP and lesser than zero on its right. The algorithm perturbs the operating point by increasing or decreasing reference voltage by small amount (Perturbation size). It measures the PV output power before and after perturbation, if the power increases it continues to perturb in the same direction, otherwise in opposite direction [13].

1. MAXIMUM POWER POINT

A typical P-V and I-V characteristics of PV module is represented in Fig. 2. The maximum power is transferred to load only when load line crosses at MPP which is defined as point at which maximum current is obtained at maximum voltage from PV panel. Since MPP changes with time during day time, a suitable tracking system to be adapted to interface PV generator. Load line can be fixed at MPP by selecting load resistance suitably. But it is impossible to maintain maximum power at this point since MPP always shifts with changes in insolation level. In order to maintain the system always operating at MPP, the load line should be shifted according to solar radiation. For example, in Fig. 2, PV module operates at point 'C' on I-V curve when the irradiance level is at 0.3 KW/m^2. Here the load line crosses at 'C' in I-V curve. The maximum power available is corresponding to point 'A' in P-V curve of irradiance level at 0.3 KW/m^2. Now if the irradiance level is changed to 0.8 KW/m^2, the operating point shifts from point 'C' to point 'E' in new I-V curve. Though MPP is at point 'B' in P-V curve of irradiance level 0.8 KW/m^2 , PV panel gives less output power corresponding to point 'F' in P-V curve. In order to get maximum power at new irradiance level the load line2 has to be shifted to new location as shown in Fig 2 (load line1) by altering the impedance of PV panel. This process is called Maximum Power Point Tracking (MPPT). P&O algorithm helps in shifting the load line if irradiance is changed. These operations can be implemented in DC-DC converter which interlinks the solar panel the load system through DC-AC converter as shown in Fig: 1

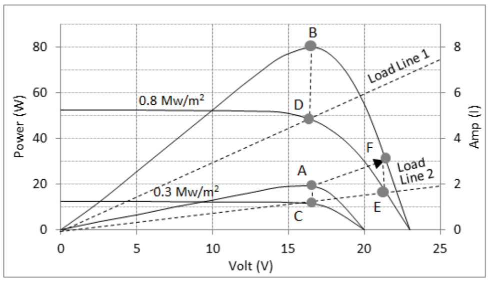

Fig. 2 Typical P-V and I-V curves of irradiation 0.8 KW/m^2 and 0.3 KW/ m^2

2. DC-DC BOOST CONVERTER

The external load is defined by the user and cannot be altered with respect to solar radiations and temperature. By using DC-DC converter, load line can be shifted by adjusting its duty cycle. This arrangement is represented in Fig. 3.

$$\frac{\mathrm{Vo}}{\mathrm{Vin}} = \frac{\mathrm{Iin}}{\mathrm{Io}} = \frac{\mathrm{D}}{1-\mathrm{D}} \quad (1)$$

$$\mathrm{V_{in}} = \mathrm{V_o}\left(\frac{1-\mathrm{D}}{\mathrm{D}}\right) \quad (2)$$

$$\mathrm{Rin} = \frac{\mathrm{V_{in}}}{\mathrm{I_{in}}} = \left(\frac{\mathrm{V_o}}{\mathrm{I_o}}\right)\left(\frac{(1-\mathrm{D})^2}{\mathrm{D}^2}\right) \quad (3)$$

Where 'D' is duty cycle of the converter, '$\mathrm{V_{in}}$' is output voltage from solar panel and '$\mathrm{I_{in}}$' is current available from solar panel.

MPP operation is based on adjustment of impedance $\mathrm{R_{in}}$. The impedance can be adjusted by varying duty cycle, so that load line can be altered. When D=1, $\mathrm{R_{in}}$ will be zero and in this condition the current '$\mathrm{I_{in}}$' is short circuited. When D=0, $\mathrm{R_{in}}$will have infinite value and in this condition it is open circuit voltage.

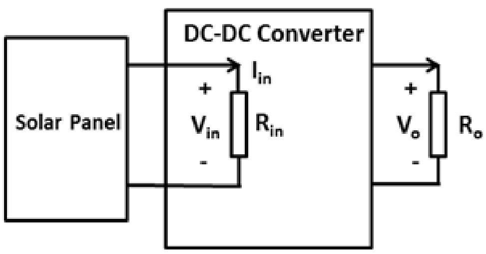

Fig.3DC-DCBoostConverter

3. NORMAL P&O ALGORITHM

The flow chart of normal P&O algorithm is as per Fig. 4 which tracks dP/dV in P-V curve and is explained with reference to Fig. 5 [14].

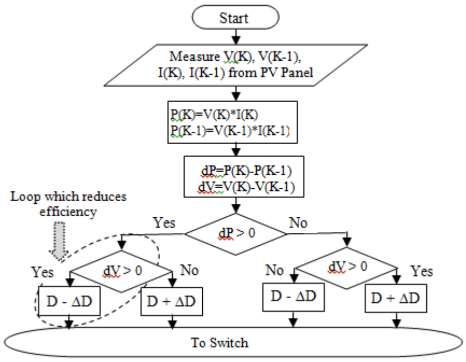

Fig. 4 Flow chart – Normal P&O algorithm [14]

In normal P&O method, a small step size is introduced to control parameters and measure the voltage and power before and after step change. If power increases, the algorithm continuous to perturb the system in the same direction, otherwise in opposite direction. In Fig. 5, at 0.3 kW/m^2 irradiations level, while PV panel operates at point '1' in P-V curve, the normal P&O algorithm moves the operating point from '1' to '2'. At point 2, $dP = (P_2-P_1) > 0$ and $dV = (V_2-V_1) > 0$. So duty cycle is reduced as per flow chart in Fig. 4 and operating point shifts to point '3'. At point '3' as $dP = (P_3-P_2) < 0$ and $dV = (V_3-V_2) > 0$, it increases duty cycle. So operating point shifts again towards point '2'. At point '2' as $dP = (P_2-P_3) > 0$ and $dV = (V_2-V_3) < 0$, it again increases duty cycle and operating point shifts towards '1'.As the algorithm continuously tracks the slope, operating point oscillates continuously between three points' 1, 2 and 3, though maximum power point is at '2'. This continuous oscillation around MPP is the first drawback of normal P&O algorithm. While operating at point '2' if irradiance increased from 0.3 kW/m^2 to 0.8 kW/m^2 MPPT algorithm shift the operating point to '4' in the new P-V curve instead of point '3'. At this point dP & dV >0, hence MPPT shift the operating point to '5' which is far away from point '6' which is MPP for new P-V curve. Here the tracking is diverted due to confusion by normal P&O algorithm. The confusion is due to the fact that it does not differentiate the increase in power is due to oscillations around MPP or due to increase in irradiance.

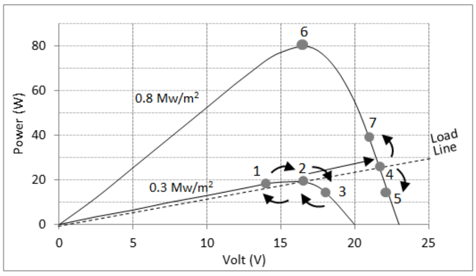

Fig. 5 PV curve – Shifting of operating point

This momentary wrong direction created by normal P&O algorithm during sudden raise in irradiance level is the second drawback. Both drawbacks contribute to loss of power output from PV panel. Several works have been addressed after modifying normal P&O algorithm to either eliminate or reduce these draw backs.

4. MODIFIED P&O ALGORITHM

4.1 Modified P&O Algorithm with 'dI' Computation

In [14] the authors suggested a modified P&O algorithm in which an additional parameter 'dI' is computed along with 'dP' and 'dV'. The flowchart is represented in Fig.6. This algorithm is explained with the help of Fig.5.When irradiance is at 0.3 kW/m^2 (Fig 5) MPPT algorithm directs operating point perturbs between points 1-2-3 in P-V curve though MPP is at point 2. While perturbing from point 2 to 3, if irradiance increases to 0.8 kW/m^2 , the operating point shifts to point 4 in P-V curve instead of point 3. This is because, the load line passes through point 2 crosses the new P-V curve at point 4. At point 4 the new algorithm checks dP which is (P4-P2) and dV which is (V4-V2). As both dP and dV are greater than zero it also checks dI which is difference between the measured current at 0.8 kW/M^2 and 0.3 kW/m^2 . Obliviously this is also greater than zero and hence it increases the duty cycle 'D'.

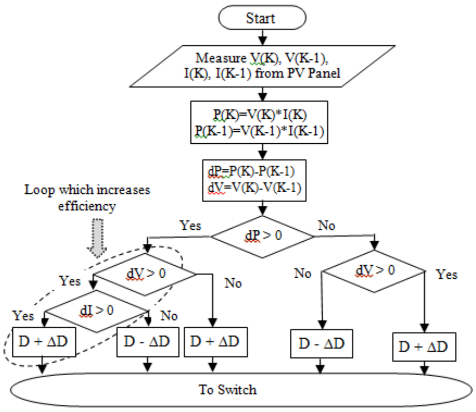

Fig. 6 Flow chart – Modified P&O algorithm [14]

As the duty cycle is increased the operating point changes the rout to point 7 from point 4 in P-V curve. It does not allow reaching point 5. By this way the wrong tracking direction is eliminated by this modified P&O algorithm and operating point moves towards MPP (point 6) during consequent iterations. As the scope of this is paper is only to eliminate drift due to wrong tracking direction, it doesn't speak about reduction in size of perturbation when the oscillations are around MPP and continuous operate in fixed perturbation size.

4.2 Modified P&O with Current Perturbation

In [15] the authors proposed the concept of normal P&O algorithm along with fractional short circuit current algorithm (FSCC). The flow chart is represented in fig.7.

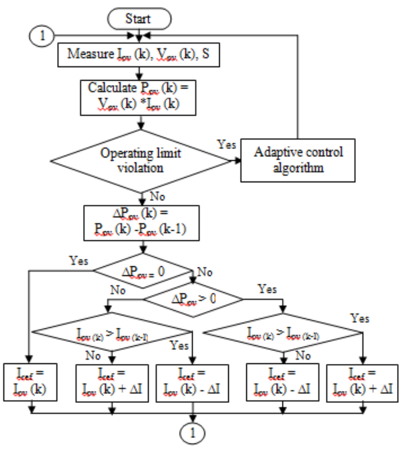

Fig. 7 Flow chart – Modified P&O algorithm with current perturbation [15]

At particular instant (k), after measuring PV panel current I_{pv} (k), voltage V_{pv} (k) and irradiance S, the proposed algorithm checks whether it operates within the limits of I_{pv} or S. If it operates within these specified limits it starts perturbation by using modified P&O algorithm. The modified P&O algorithm differs from normal P&O algorithm by having current perturbation instead of voltage perturbation to track power towards MPP. It is justified using current perturbation which is explained as follows with respect to P-V and I-V curves in Fig.8

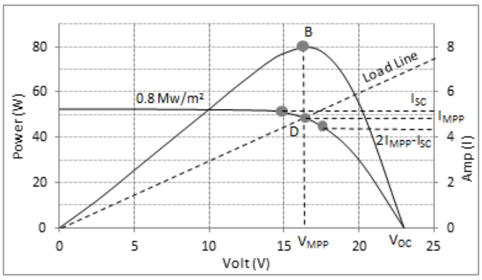

Fig. 8 P-V and I-V curves – Modified P&O algorithm with current perturbation

In Fig.8, point B and D are maximum power point voltage (V_{MPP}) and current (I_{MPP}) in P-V and I-V curve respectively. The load line crosses at point D where maximum power is available from PV panel.

In I-V curve, current in the left hand side of MPP (point D) is almost constant and the difference between Isc and I_{MPP} is smaller when compare with the difference between V_{MPP} and V_{OC} in P-V curve. Hence the algorithm shifts the operating point at MPP quickly when current perturbation is considered. On the other hand, in I-V curve, the difference in current between I_{MPP} and any operating point at right side of MPP is much larger. Hence to make the current perturbation faster a lower boundary is introduced at $2I_{MPP}$-I_{sc}. Between these boundary limits, the current perturbation is considered to be faster than voltage perturbation. Hence modified algorithm with current perturbation tracks MPP faster between these limits. Further it suggests variable perturbation size (ΔI) and it is proportional to irradiance level.

At particular irradiance, threshold current change (ΔI_T) is the difference between short circuit current (I_{SC}) and lower boundary current I_l, ($I_l = 2I_{MPP}$-I_{sc}).

$$\Delta I_T = I_{SC} - (2I_{MPP} - I_{SC}) = 2(I_{SC} - I_{MPP}) \quad (4)$$

According FSCC method I_{SC} has following linear relation with I_{ref}

$$I_{ref} = m * I_{SC} \quad (5)$$

Where m is proportionality constant and I_{ref} is the reference current which is to be made equal to I_{MPP}. Hence substituting (5) in (4), we get.

$$\Delta I_T = 2(I_{SC} - mI_{SC}) \quad (6)$$

From the above equation it is seen that ΔI_T is proportional to short circuit current I_{SC}. Since I_{SC} is proportional to irradiance S, ΔI_T is proportional to S. Hence at each and every iteration the perturbation size is varied. As this modified P&O algorithm tracks between current limits, if the current limit exceeds due to sudden change in irradiance level, adaptive control algorithm (ACA) tracks the power. This is based on FSCC algorithm and I_{ref} will be directly proportional to I_{SC}. ACA will only activate once there is an abrupt change in irradiance.

4.3 MODIFIED P&O WITH REAL TIME SIMULATION

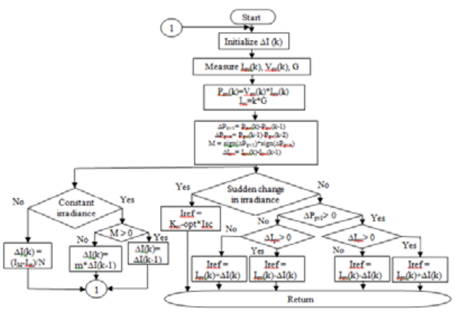

Fig. 9 Flow chart – Modified P&O algorithm with real time simulation [16]

In [16] the authors suggested a hybrid MPPT technique which has the same concept mentioned in [15] but it differs in calculating variable perturbation size and also it reduces oscillations at every iteration when the oscillations are around MPP. The flow chart is as per Fig.9.

To calculate variable perturbation size which is ΔI, the algorithm decides whether irradiation is constant or not. If it is not constant it uses the following relation to calculate ΔI.

$$\Delta I(k) = (I_M - I_m)/N \quad (7)$$

Where 'I_M'and 'I_m'are constants which represent maximum and minimum value of perturbation current respectively. 'N' represents maximum number of iterations required to reach MPP which is also constant. On the other hand, if irradiation is constant, the algorithm checks for the oscillations. To find whether the oscillations are around MPP or not, the sign variable M is used.

$$M = \mathrm{sign}\Delta P_{pv1} - \mathrm{sign}\Delta P_{pv0} \quad (8)$$

Where $P_{pv1} = P_{pv}(k) - P_{pv}(k\text{-}1)$ and $P_{pvo} = P_{pv}(k\text{-}1) - P_{pv}(k\text{-}2)$

When operating moves around MPP, after two iterations, M value becomes zero as the sign value is positive in first iteration and negative in second iteration. Hence perturbation size ΔI is reduced by factor m. By this way the perturbation size is dynamically reduced when operating point oscillates around MPP. This operation is summarized in Table.1. All other operations are similar to flow chart mentioned in [15].

Table: 1 Perturbation size depending upon sign variable M

Sign ΔP_{pv1}	Sign ΔP_{pv0}	I(k)
1	1	ΔI (k-1)
1	-1	m*ΔI (k-1)
-1	1	m*ΔI (k-1)
-1	-1	ΔI (k-1)

4.4 Modified P&O algorithm with variable perturbation size

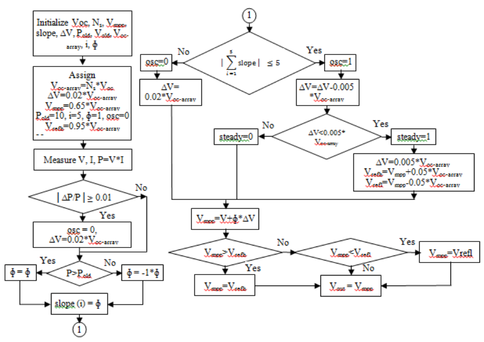

Fig. 8 Flow chart – Modified P&O algorithm with variable perturbation size [17]

In [17] the authors suggested modified P&O algorithm with variable perturbation size. The flow chart is as per Fig.8. Here perturbation size is dynamically altered while tracking towards MPP. Also they introduced upper and lower boundaries in P-V curve in order to avoid divergence of operating point during sudden raise in irradiance. Initially the perturbation size is set at 2% of Voc-array ($V_{oc\text{-}array} = N_s * V_{oc}$). Where V_{oc} is open circuit voltage and N_s is number of solar cells in series. It is assumed that change in irradiance is related with change in power which is considered to be 'slow' if it is <10 W/m^2/s. Rather if the change is >10 W/m^2/s, it is considered to be 'fast'. For example if change in power at any two instants is 20 W/m^2 (P1=1000 W/m^2 P2=1020 W/m^2), the algorithm checks with respect to following condition which is derived from current equation of PV panel.

$$\left| \frac{\Delta P}{P1} \right| \geq 0.01 \quad (9)$$

$$\left| \frac{20}{1000} \right| = 0.02 \geq 0.01 \quad (10)$$

Since the normalized power is greater than 0.01, the algorithm considers it as 'fast' change and retain ΔV at 2% of $V_{oc\text{-}array}$. Further, up to five times the change in power (ΔP) is checked. The value of ϕ is sign multiplication of these quantities (ΔP) and normalized to unity.

4.5 When oscillations are around MPP:

In P-V curve, after reaching MPP, the operating point moves two times in one direction and then to opposite direction. As a result the value of ϕ is always less than five after five iterations. If this is less than five, the algorithm assumes the perturbation is around MPP and decrease ΔV value at the rate of 0.005 at each iterations till it reaches to 0.05% of Voc-array. By this way the oscillations around MPP is reduced to minimum value. Further reduction is not suggested since MPP is not always constant and there will always be change in G. This small change in G will not induce a sudden change in power. Fixing at zero perturbation will force the MPP stick at same voltage all over the period though the actual voltage is varying. Hence it is important not to have zero perturbation. When minimum value of ΔV is reached, the steady flag is toggled to 1 and following boundaries are set in P-V curve.

Left side Boundary = V_{mpp}-0.05* $V_{oc\text{-}array}$
Right side boundary = V_{mpp}+0.05* $V_{oc\text{-}array}$

These boundaries are set to avoid tracking direction during sudden rise in irradiance. When there is a rise in irradiance, the operating point slightly shifts towards right. Here the algorithm compares V_{mpp} (maximum possible voltage which is 65% of $V_{oc\text{-}array}$) with V_{refh} (right side boundary voltage). If $V_{mpp}>V_{refh}$, it decides V_{out} as V_{refh}, otherwise it retains V_{mpp} for V_{out}.

4.6 When oscillations are not around MPP:

This condition is detected when ϕ value becomes five after five iterations. In this condition ΔV is set at initial condition (2% of $V_{oc\text{-}array}$) and V_{out} will be V_{mpp}. Within the imposed boundary the algorithm tracks MPP either with minimum perturbation size or maximum perturbation size.

Thus the algorithm reduces the oscillations around MPP by reducing ΔV value at each iteration and also imposing boundaries in P-V curve to avoid tracking misdirection.

5. CONCLUSION

This review paper provides brief description about improved methods of different P&O algorithms for tracking maximum power in photovoltaic panel. One of the root causes for not having ripple free power at the generation side of PV system is improper tracking techniques. As the P&O algorithm is renowned for its simplicity, its demerits to be addressed and eliminated for successful implementation. Sufficient research works have been done and many research articles published in the past. Though the ultimate aim of all published articles are unique to eliminate the drawbacks, each article has its own approach and are not unique in nature in its approach. As discussed in this article, some articles suggested boundaries in P-V and I-V curves to avoid wrong tracking direction while others suggested additional loop in the original algorithms. Some articles suggested hybrid techniques also. To reduce operating point oscillations around MPP, some of them suggested optimum constant perturbation size, some articles developed variable perturbation size by measuring irradiance and some articles relate irradiance with output power and avoids measuring irradiance. All these details have been discussed in this paper and it is difficult to comment on which method is superior over the other. However, without compromising the originalities of P&O algorithm, there are further scopes to strengthen P&O algorithm for efficient tracking.

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