DESIGN AND IMPLEMENTATION OF CROW SEARCH ALGORITHM TUNED MPPT CONTROLLER FOR GRID CONNECTED PV SYSTEM

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Abstract: This paper presents the Crow Search Algorithm (CSA) based Maximum Power Point Tracking (MPPT) scheme for solar PV system integrated with utility grid. Incremental conductance based MPPT is used in PV system and its limitations will be overcome by introducing Integral regulator at the grid side. In this work, CSA has been implemented to tune the gain values of the integral regulator at source side and that of the DC voltage regulator at grid side simultaneously based on an optimization criterion for minimizing power error in source side. The static and dynamic power tracking capability of the proposed technique is tested in MATLAB simulation under constant load with variable irradiation conditions.

Key words: *Photovoltaic (PV) system, crow search algorithm, incremental conductance, integral regulator, maximum power point tracking.*

1. Introduction

PV power feedings to utility grid is getting wide attention due to invention of efficient power electronic conversion devices. The grid connected system shall operate at maximum power to meet the increasing load demand. Under constant irradiation conditions, it can deliver maximum power but in variable irradiation conditions, the maximum power could not be delivered without a required maximum power point tracker. A grid connected PV system consists of two controllers, one at source side and the other at grid side. The two controllers must operate with proper coordination to deliver maximum power at the load side.

The various technical analyses on MPPT techniques for solar PV based power generation are mainly focused on control variables, control techniques and practical implementation strategy [1]. The delivered power from PV system depends on irradiation level. But the irradiation values will vary continuously over a time interval. A MPPT

controller based on voltage-oriented control was developed for a PV system considering the fast changing irradiation values [2].

A maximum power point tracking algorithm based extremum seeking controller that utilizes the natural inverter ripple to optimize solar array performance under variable irradiation conditions have been reported in [3]. Apart from that, a three-level three-phase neutral point clamped voltage source inverter is implemented for interfacing the PV system to utility grids. A complex switching technique to control the dc-link neutral-point voltage is not required for this method [4].

Implementation of soft computing techniques in MPPT controller is becoming popular and useful for better control in solar PV systems, due to its flexibility and non-linear controllability. A robust soft computing method based MPPT algorithm for PV system has been implemented incorporating partial shading and variable irradiance constraints [5-6]. A, fuzzy logic based MPPT controller has been developed for three-level grid interactive inverter system [7]. Here, the fuzzy controller improves the hill-climbing search based maximum power tracking technique. Fuzzy logic based hill climbing technique provide accurate tracking for maximum operating power during dynamic atmospheric conditions [8].

A tracking method based on particle swarm optimization algorithm was developed for fast and effective power point tracking for a PV system [9]. Among the various MPPT methods, the incremental-conductance algorithm is widely used, due to its high tracking accuracy. A variable step-size incremental-resistance MPPT algorithm has been developed for a typical photovoltaic system, which provides better results [10-12].

Also, various research works have been reported in literature, based on techniques namely-Lagrangian Interpolation technique, Fibonacci

search, Cuckoo search, Genetic algorithm and various ANN based MPPT controllers [13-22]. Among these techniques, Incremental conductance method is highly suitable for power point tracking in PV systems [23-25]. This method has few limitations: slow tracking, less accuracy etc. However these limitations can be overcome by introducing integral controller at the grid side. In this control, the controller gains are of fixed values, which will not be suitable for varying irradiant conditions [26-28]. Based on these facts, in this work, crow search algorithm is implemented to tune the controller gain values based on dynamic irradiations and minimum developed power error. The proposed CSA tuned MPPT controller is implemented and tested in a grid connected PV system. Also the simulation results of the proposed CSA tuned variable gain- Incremental conductance controller (CSA+ VGIC) are compared with Incremental conductance (IC) and Incremental conductance with constant gain (CGIC) based controllers.

2. Photo voltaic model

PV power module uses two or more solar panels to convert solar energy into electrical power. The PV module has emerged as an effective and economical alternative source of renewable power generation. An equivalent circuit model of photovoltaic cell is shown in Figure 1.
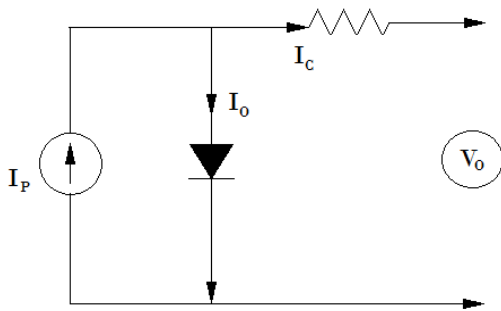

Figure1. Equivalent circuit of photovoltaic cell.

The modeling of PV module involves developing basic voltage equations of photovoltaic cells including the effects of temperature changes and solar irradiation [29]. The PV cell output voltage is a function of photo current, which is determined by load current based on solar irradiation level during its operation. The solar cell output voltage V_C can be calculated using Equation 1.

$$V_c = \frac{AKT_c}{e} \ln\left(\frac{I_{ph} + I_o + I_c}{I_o}\right) - R_s I_c \tag{1}$$

Where K is Boltzmann constant (1.38×10^{-22} J/ k, e is electron charge (1.602×10^{-19}c), I_{ph} is photo current. I_0 is reverse saturation current of diode. Rs is solar cell internal resistance, A is fitting factor, Ic being cell output current in A and Tc is operating temperature of reference cell at 40^oC. Based on changes in irradiation and solar cell operating temperature, photo current and output voltage can be calculated. A I-V and P-V characteristics of a typical 100kW sun power model are shown in Figure 2.

(a) Individual cell characteristics
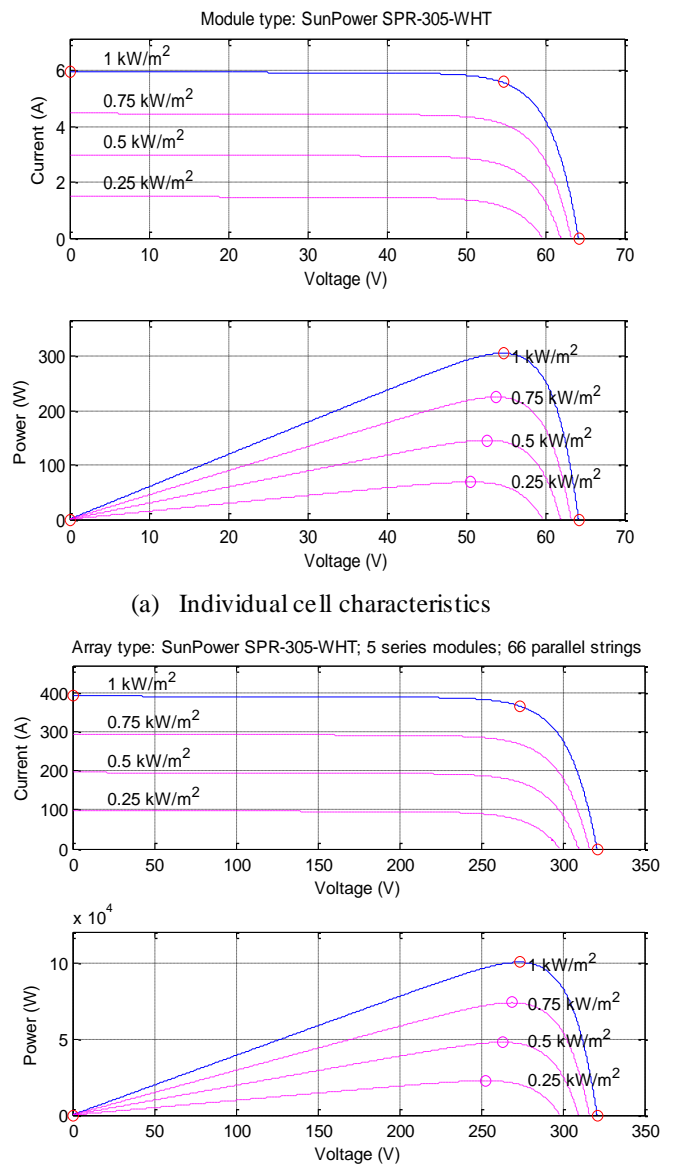
(b) Total PV generation system characteristics

Figure 2. IV and PV charcteristics of PV module

3. Proposed MPPT System and optimization criterion

The proposed MPPT system in figure 3 consists of PV system, boost converter, three level inverter, VSC controller at grid side, incremental conductance- MPPT controller and Crow search algorithm for tuning. The boost converter boost the variable PV voltage to a certain value and gives to the inverter, connected to utility gird. The proposed optimization criterion is set as follows:

$$f = \min(e + e_1) \qquad (2)$$

subject to

$$K_i^{min} \leq K_i \leq K_i^{max}$$

The objective here is to minimize the power error $(e+e_1)$ for better power tracking ability. The constraints K_1, K_2, K_3 (i=1,2,3) is based on Incremental conductance gain in source side, Gain values (K_2 and K_3) of PI controller in grid side respectively. The range of gain values were selected as $(0 - 30)$ for tuning during simulation. The error variables are defined by:

$$e = \frac{\Delta I_{PV}}{\Delta V_{PV}} + \frac{I_{PV}}{V_{PV}} \qquad (3)$$
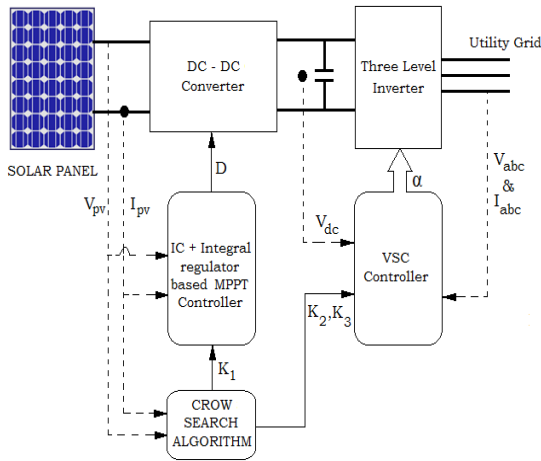
$$e_1 = V_{dcref} - V_{dc} \qquad (4)$$

Figure 3. Proposed MPPT system

In this work, initially the source power error 'e' and dc link voltage error 'e₁' are calculated with fixed gain values and the error can be reduced to zero / minimum value by CSA implementation.

4. Crow Search Algorithm- An overview.

Crows are considered to be the most intelligent birds, having intelligent brain compared to other birds. Crows predict the unfriendly situation easily as they have strong face recognition ability. Crows have been known to watch other birds, and where other birds hide their food. Once the birds leave from a place, it can easily steal the food. It will search their food by communicating every move to their families in an optimized way. Based on these special qualities of crows, CSA have been developed by researchers [30].

The following parameters are considered for implementing the crow search algorithm. Number of crows assigned as flock size (N), position of crow i at time (iteration) k in search space, Maximum iteration M. Each crow has a memory in which the position of its hiding place is memorized. At iteration k, the position of hiding crow i finding at $m^{i,k}$. This is the best position that crow i has obtained.

Assume that at iteration M, crow j wants to track the hiding place, $m^{i,k}$. Now crow i decide to follow crow j to reach to hiding place of crow j. In these processes, two conditions may happen:

Condition 1: Crow j does not know the crow i is following it. As a result, crow i will track the hiding place of crow j. Now, the new position of crow i is obtained as follows:

$$x^{i,k+1} = x^{i,k} + (r_i \times f^{i,k}) \times (m^{i,k} - x^{i,k})$$

$$(5)$$

Where r_i is a random number with uniform distribution between 0 to 1 and flight length of the crow i at iteration k is denoted as $f^{i,k}$.

Condition 2: Crow j knows that crow is following it. In order to protect its cache from being pilfered, crow j will fool crow i by going to another position in the search space.

Combining the 2 conditions,

$$x^{i,k+1} = \begin{cases} x^{i,k} + (r_i \times f^{i,k}) \times (m^{i,k} - x^{i,k}) & r_j \geq AP^{i,k} \\ a \ random \ position & otherwise \end{cases} \quad (6)$$

Where r_j is a random number with uniform distribution between 0 and 1 and awareness probability of crow j at iteration k is represented as $AP^{i,k}$.

5. Proposed CSA to determine optimal gain values for better tracking ability

CSA has been simulated in MATLAB software to compute the optimal gain values of the MPPT controller. The computational steps implemented for the same is given here.

Step1: Initialize flock size, maximum iteration, flight length, awareness probability and the decision variables (K_1, K_2, K_3).

Step 2: Initialize the position and memory of crows in three dimensional search space.

Step 3: Evaluate the fitness function as given in equations 2, 3 and 4.

Step 4: Update the memory as follows

$$m^{i,k+1} = \begin{cases} x^{i,k+1} & F(x^{i,k+1}) \text{ is better than } F(m^{i,k}) \\ m^{i,k} & otherwise \end{cases} \quad (7)$$

If the fitness function value of the new position of a crow is better than the fitness function value of the memorized position, the crow updates its memory by the new position.

Step 5: Crows generate the new position in search space as crow i need to generate a new position. This crow randomly selects one of the flock crows and follows it to discover the position of hidden foods. This process is repeated for all the crows.

Step 6: The feasibility of the new position of each crow is checked. If the new position of a crow is feasible, crow updates its position otherwise the crow stays in the current position.

Step 7: Evaluate the fitness function again.

Step 8: Steps 4-7 are repeated until iteration reaches the maximum iteration value. The best position of the memory in terms of the objective function values is computed as the optimized gain values of the controller.

6. Simulation Results and discussion

To validate the performance of the proposed MPPT controller, dynamic simulation experiments has been carried out in MATLAB environment under variable irradiation conditions. The performance of the proposed MPPT controller has been tested with 100kW PV generation system tied with 20kV/100kVA overhead transmission line.

Table 1 gives the parameters selected for CSA implementation and the computed optimal gain values of the controller. Figure 4 shows the convergence rate of the CSA for finding the optimal gain values of the MPPT system.
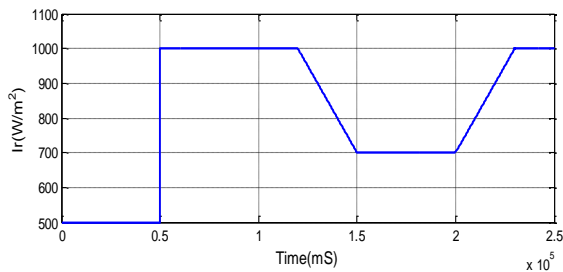
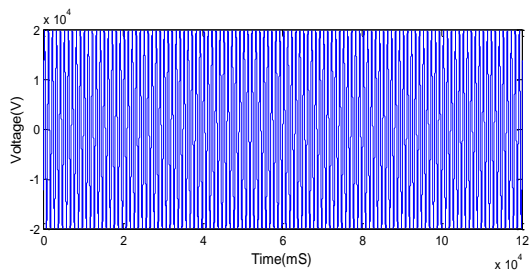| S. No	CSA parameter	Values implemented	Initial fixed values	Computed Optimal gain values from CSA
1	Flock size	20		
2	Flight length	2		
3	Awareness probability	0.15	$K_1 = 3$ $K_2 = 5$ $K_3 = 10$	$K_1 = 7.4$ $K_2 = 8.7$ $K_3 = 16$
4	No. of variables	3		
5	Max iterations	50		
6	Termination condition	Max. No. of iterations.		

Table:1 CSA parameters and optimal gains computed
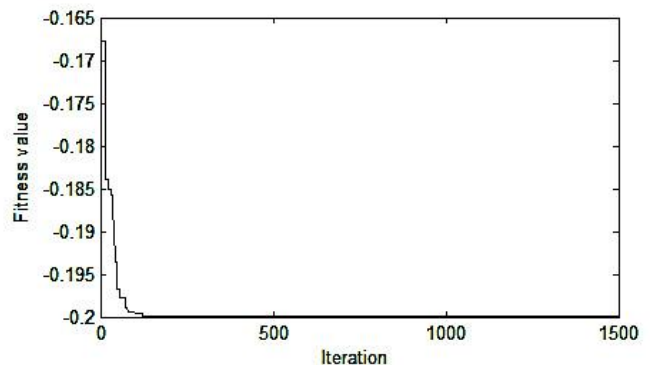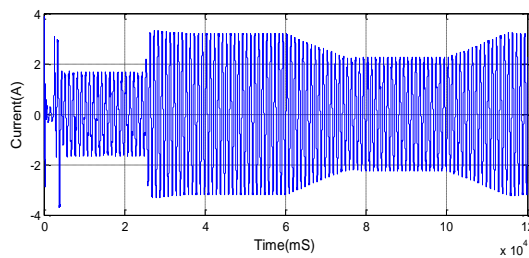

Figure 4. Convergence rate of CSA

The following results are brought out for testing the performance; grid voltage and current, three level inverter output voltage, power tracking ability in both steady state and dynamic states. Figure 5 shows the dynamic state of irradiation level with respect to time. Figure 6 (a and b) represents the 500 V three level voltage source inverter output voltage waveform.
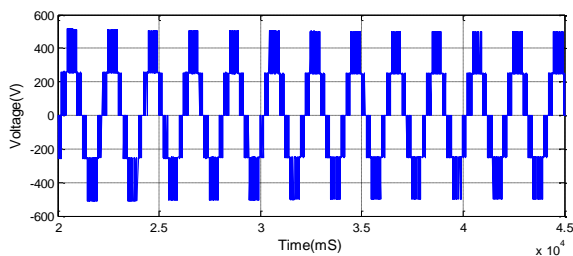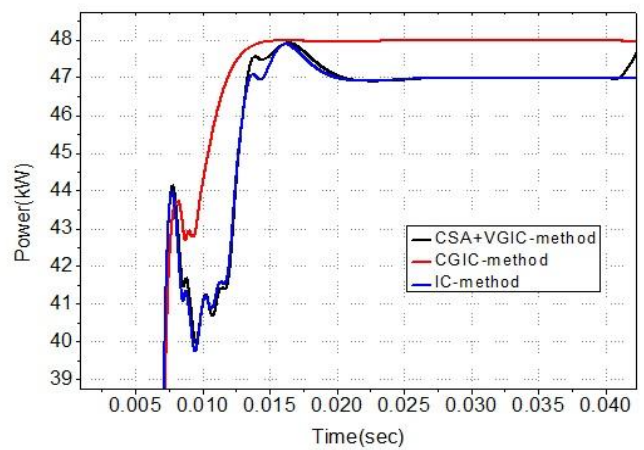
Figure 7 illustrate the 20kV grid voltage and current dynamic state with respect to irradiation conditions. PV power tracking performance of three different MPPT controllers has been compared and its results are shown in figure 8. Figure 8(b) shows the enlarged scale PV power value at 500 w/m^2 irradiation conditions and figure 8(c) shows the enlarged scale PV power value at 1000 w/m^2 irradiation condition.
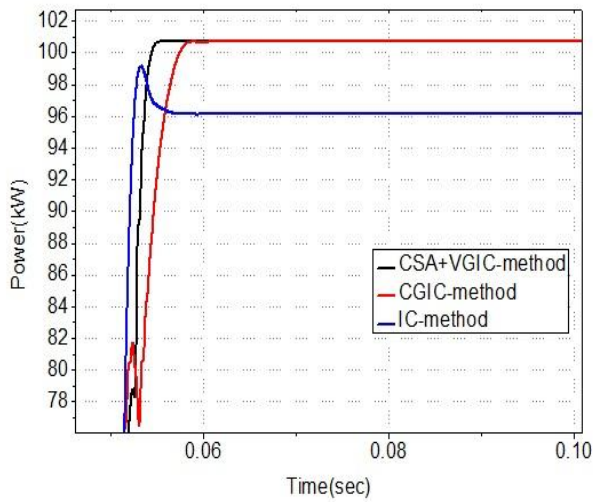
The proposed Crow Search Algorithm Based Variable Gain Incremental Conductance (CSA+VGIC) MPPT controller gives better tracking performance in terms of less steady state power error and fast transient tracking ability compared with other two controllers namely: Incremental Conductance(IC) and Incremental Conductance with constant gain (CGIC).

Figure 5. Irradiation level of the PV panel

(a)

(b)

Figure 6: Grid phase voltage and current

**Figure 7: Three-level Inverter output voltage**
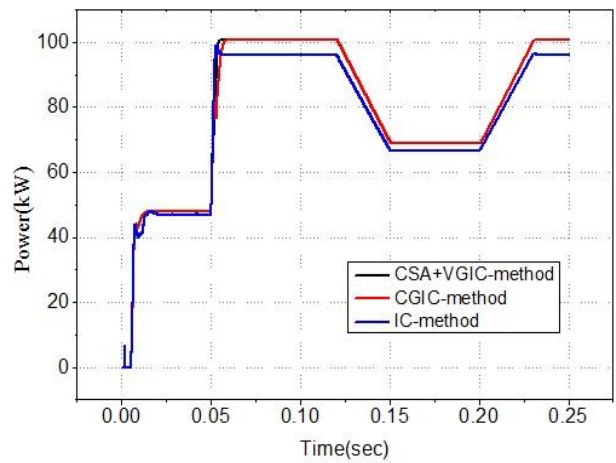
(a)

(b)

(c)

Figure 8: Simulation results of three MPPT controllers (a) PV Power (b) PV power zoomed for 48kw(500 W/m²) (c) PV power Zoomed for 100kW (1000 W/m²)

Under steady state conditions, IC and CGIC MPPT controller gives 47kW of power and the proposed (CSA+VGIC) MPPT controller gives 48kW at 500 W/m² irradiation level. Under transient condition, the proposed MPPT controller track the maximum power at very fast time 0.010 sec, but conventional controller has reached maximum power at 0.020 sec and also the proposed controller have less oscillation, peak , under overshoot values compared to conventional methods.
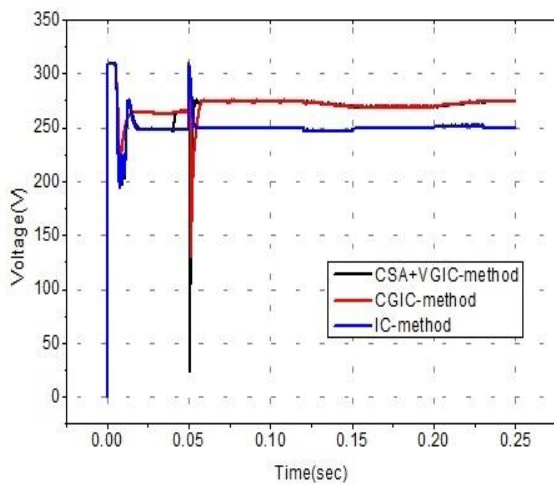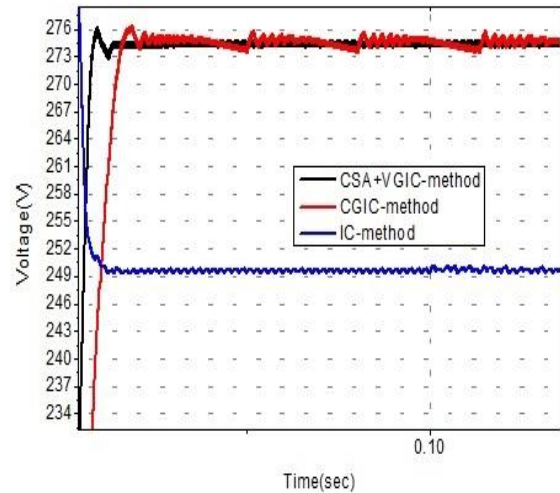


(b)

Figure 9: (a) Simulated voltage for the PV generator for three MPPT controllers (b) zoomed voltage at 1000 W/m² for 273.5 volts.

Figure 9 (a,b) shows the PV voltage at variable irradiation levels. Figure 9 (b) shows the enlarged scale values of the voltage at 1000 W/m². The IC MPPT gives 249 volts, CGIC MPPT gives 274 Volts with certain interval oscillation and the proposed MPPT controller gives 273.4 volts exactly as per design. The current profile of generation side is shown in figure 10. Different irradiation level current waveforms shown in figure 10(b) and 10(c) show that the proposed tracking controller have better performance compared to conventional controllers and due to its minimum current value, the devices experienced less stresses.

(a)
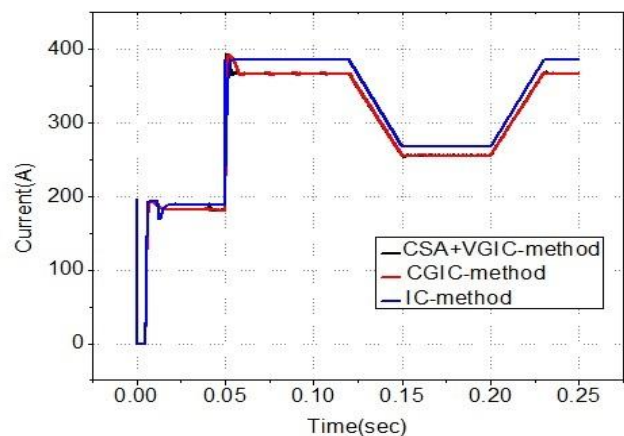
(a)
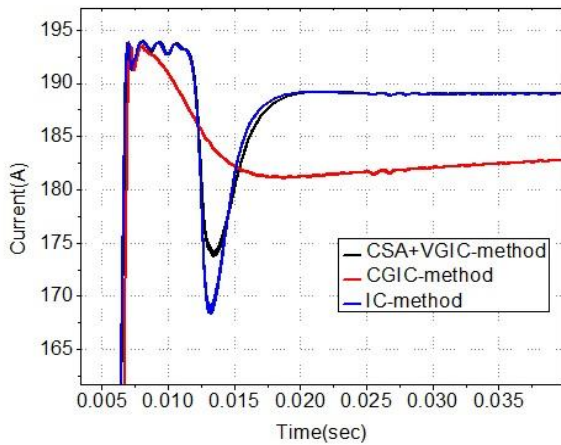
(b)
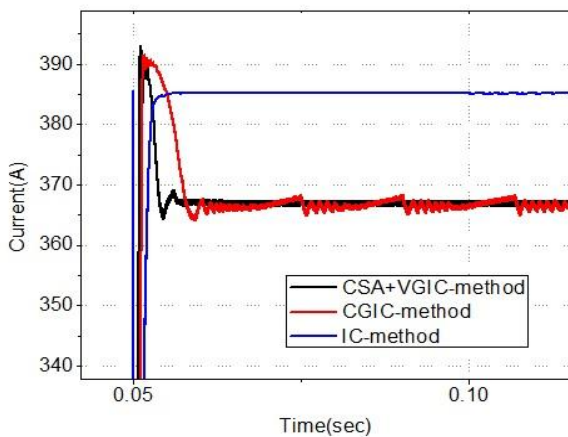
(c)

Figure 10.Simulation results of three MPPT controllers (a) PV current (b) PV current zoomed at 48kW (c) PV current zoomed at 100kW

Figure 11. DC link voltage of the multilevel inverter for different MPPT controller

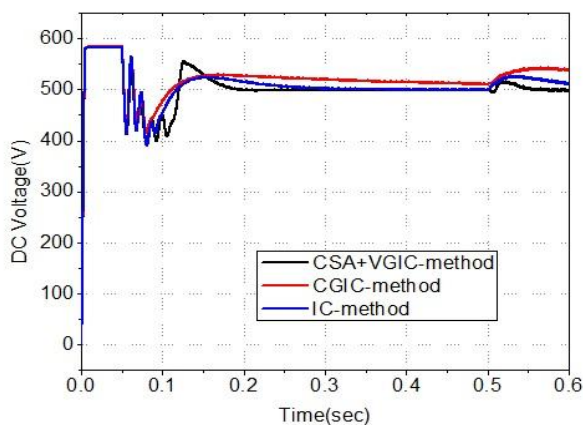The DC link voltage of the system is shown in figure 11. The proposed MPPT controller has less peak overshoot, less transient oscillation and constant DC voltage compared to conventional controllers. These simulated responses clearly indicate the proposed CSA tuned MPPT controller exhibits better power tracking performance than IC and constant gain IC controller.

7. Conclusion

In this paper, a novel MPPT controller tuning algorithm was proposed for PV system tied with utility gird. The CSA has been successfully implemented for simultaneously tuning the controller gain values of the MPPT controller at source side and VSC at grid side. This method is based on generating global search space as like crow food space to compute the global minimum controller gain values as like finding shortest path from nest and food in a crow colony. The gain values in the Inc integrator and DC link voltage regulator has been dynamically varied with respect to irradiation level and power error values are computed. The reported simulation results on the test power system validate that the proposed MPPT controller have fast and accurate maximum power tracking ability compared with conventional controllers and well suited for highly variable irradiation conditions.

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