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Load Current Adaptive Step Size and Perturbation Frequency (LCASF) MPPT Algorithm or Adaptive Step Size with Adaptive Perturbation Frequency Scheme for Grid Connected PV System

Rachna Verma, Anjali Potnis

Abstract: ***This paper deals with the growing electricity demand along with reduction in conventional fuel sources and growing environmental concerns, the renewable energy sources like wind power , solar power, hydro power , geothermal , biomass are globally welcomed to replace the conventional power sources. Among the different methods of generating electric power by alternative resources, photovoltaic (PV) has grown steadily in recent decades as one of the best technology alternative because it is free, abundant, pollution free and most widely distributed. Photovoltaic (PV) grid connected system is the trend of solar energy application. Photovoltaic (PV) is a technique of converting solar radiation into direct current electricity to generate electricity using semiconductor. The total amount of energy which is irradiated from the sun to the earth's surface equal's approximately 10,000 times the annual global energy consumption. But a typical solar panel converts only 30 to 40 percent of the incident solar irradiation into electrical energy. Maximum power point tracking technique is used to improve the efficiency of the solar panel. The proposed work is validated by simulating it for different load configurations using Matlab and the simulation result verifies the efficiency of proposed algorithm***

Keywords: power system grid, photovoltaic grid, solar panel, MPPT.

I. INTRODUCTION

PHOTOVOLTAIC (PV) panels are used to convert solar energy into electric power. The output characteristics of a solar PV panel are dependent on operating conditions such as irradiance level and surrounding temperature . Maximum power points (MPPs) exist on the PV panel characteristic curves where the output power from the solar panel is maximum. Maximum power point tracking (MPPT) algorithms and techniques such as perturb and observe (P&O) algorithm, incremental conductance (InCond) algorithm, ripple correlation control (RCC) algorithm , fractional voltage/current MPPT method and neural-network (NN)-based MPPT control have been developed to extract the maximum power from the PV panel. The P&O method, which locates the MPP using the slope of the *P*–*V* characteristics curve, is widely used due to its simplicity and ease of implementation.

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A disadvantage of the P&O algorithm is that the PV panel operation points oscillate around the MPP which causes energy loss. InCond algorithms overcome the drawbacks of P&O algorithms by eliminating the oscillations around the MPPs. However, since the In Cond MPPT algorithm needs realtime calculation of the slope of the PV panel power curve, it is more complicated to be implemented in controller compared to the P&O algorithm. The RCC MPPT algorithm utilizes the derivatives of the power converter's voltage and current ripples to determine the position of the PV panel operating point.

II. LITERATURE SURVEY

Because of the emerging demand cloud services every field related to it gaining interest of researchers and the load balancing is not an exception so many literatures have been already published some of them are presented in this section. **Gomathy-Saravanan-Thangavel, [2012]** This literature presented the Matlab/simulink arrangement of perturb and observe (P and O) and incremental conductance (INC) MPPT algorithm which is responsible for driving the dc-dc boost converter to track maximum power point (MPP).Also , the theoretical analysis of variable step size(VSS) of INC MPPT which can effectively improve the tracking speed and accuracy of maximum power was presented. P and O and Fixed step size INC and VSS INC MPPT methods are implemented with MATLAB-SIMULINK for simulation. **Liu-Duan-Kang, [2008]** analyzed a modified variable step size INC MPPT algorithm , which automatically adjusts the step size to track the PV array maximum power point. Compared with the conventional fixed step size method, this approach effectively improved the MPPT speed and accuracy simultaneously. Furthermore, it was simple and easily implemented in digital signal processors.**Mei-Shan-Liu-Guerrero, [2011]** analyzed a novel variable step-size incremental-resistance MPPT algorithm, which automatically adjusts the step size to track the PV array MPP. Compared with the variable step-size INC method, this scheme greatly improved the MPPT response speed and accuracy at steady state simultaneously. Moreover, it was more suitable for practical operating conditions due to a wider operating range.

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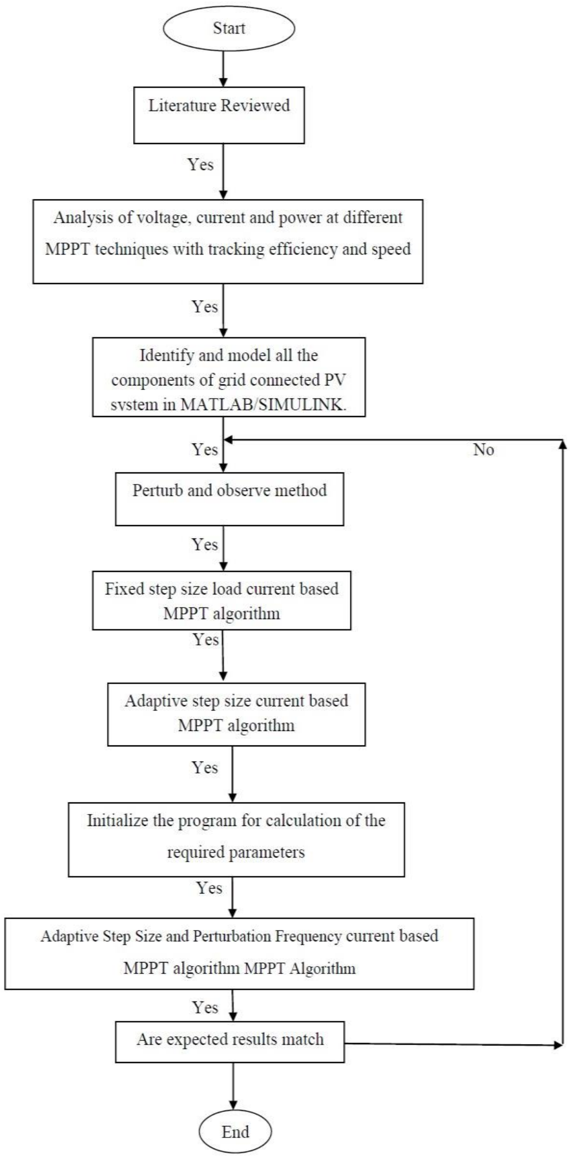
Mahdi, [2010] Improved maximum power point tracking (MPPT) algorithm of a Photovoltaic system under real climatic conditions is proposed. The proposed MPPT is based on the perturbation and observation (P and O) strategy and the variable step method that control the load voltage to ensure optimal operating points of a PV system. Mathematical models of a PV panel and a DC-DC boost converter are introduced. The system transfer function is used to optimally select the parameters of the DC-DC boost converter. A P and O strategy with the variable step method has been adopted for implementing the MPPT algorithm. **Prakash-Kumaravelan, [2014]** proposed modelling and simulation of Grid Connected Photovoltaic (PV) system by using improved mathematical model. The proposed model is used to study different parameter variations and effects on the PV array including operating temperature and solar irradiation level. **Pandirajan, [2011]** Unique step-by-step procedure for the simulation of photovoltaic modules with Matlab/ Simulink is presented here. One-diode equivalent circuit is employed in order to investigate I-V and P-V characteristics of a typical 36 W solar module. The proposed model is designed with a user-friendly icons and a dialog box like Simulink block libraries. The Photovoltaic module equivalent circuit and equations for IPV the output current from the PV module is described here. The reference model presented provides data for Solar make 36 W PV modules for simulation. Based on the above listed literature survey following problem statement for the research is formulated,

III. PROPOSED ALGORITHM

The proposed load-current adaptive step-size and perturbation frequency (LCASF) MPPT algorithm adaptively generates large perturbations with longer perturbation periods during transients to achieve fast and stable dynamic response and generates small perturbations with shorter perturbation periods that results in high efficiency and lower oscillations during steady-state operation. The trade-off between fast dynamic response and high efficiency steady-state operation with lower oscillations around the MPP for the load-current-based MPPT method is addressed in this research by developing and using an adaptive-step-size and perturbation-frequency MPPT algorithm. The proposed LCASF MPPT algorithm utilizes an adaptive-perturbation frequency scheme with higher perturbation frequency when the perturbation is smaller, and vice versa.

IV. RESEARCH METHODOLOGY

MATLAB 2011a version was used to implement this research work. Modelling of all the components of the 100kw grid connected system along with the programming in MATLAB function is done. The assessment of the results and their respective graphs obtained with proposed "Adaptive step size and adaptive perturbation frequency based MPPT algorithm" are plotted with respect to time in seconds from the workspace of the MATLAB. The flow chart of the research methodology adapted in this research is shown in figure below. From the beginning of study of fixed and variable duty cycle to the result comparison, this research tries to develop the simple, practical algorithm for different parameters of the PV array by taking care of the practical uncertainties in the system with the proposed "Adaptive step size and adaptive perturbation frequency based MPPT algorithm".



V. IMPLEMENTATION

This section illustrates the implementation and result of proposed "Adaptive Step Size with Adaptive Perturbation Frequency MPPT controller for the grid connected PV system". The algorithm for Adaptive Step Size and Adaptive Perturbation Frequency is discussed step by step with flow chart and relevant waveforms.

PROPOSED SYSTEM DESCRIPTON

The model consists of 100 kW photovoltaic array connected to a 25 kV grid via a DC-DC boost converter and a three-phase three-level Voltage Source Converter (VSC).Maximum Power Point Tracking (MPPT) is implemented in the boost converter by means of coding using the "Load Current based adaptive step size and adaptive perturbation frequency" algorithm given in the reference paper.

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Photovoltaic array delivering a maximum of 100 kW at 1000 W/m2 sun irradiance and 5-kHz boost converter increasing voltage from Photovoltaic natural voltage (272 V DC at maximum power) to 500 V DC. The Switching duty cycle is optimized by the maximum power point tracking (MPPT) controller that uses the "Load Current based adaptive step size and adaptive perturbation frequency" Utility grid connected maximum power point tracking based photovoltaic system model of 25 kV distribution feeder plus 120 kV equivalent transmission system. algorithm and 1980-Hz (33*60) 3-level 3-phase voltage source converter. The Voltage source converter converts the 500 V DC to 260 V AC and the keeps unity power factor. The 10-kvar capacitor bank filtering harmonics produced by voltage source converter and used 100 kVA 260V/25kV three-phase coupling transformer with

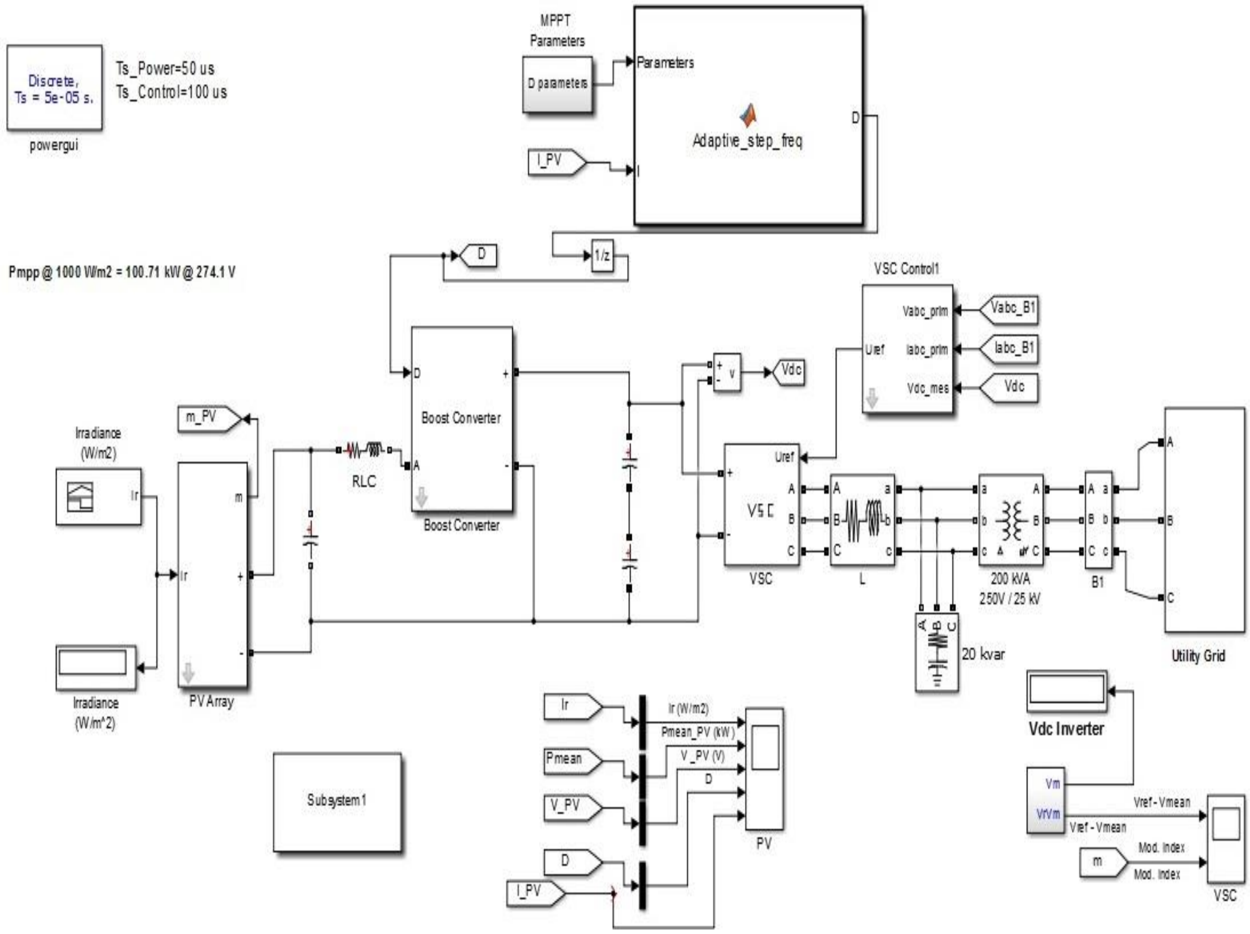

Figure Simulink model of 100kw grid connected adaptive step size and adaptive perturbation frequency MPPT algorithm based photovoltaic system

CALCULATION OF THE PARAMETERS

To run the current based adaptive step size and adaptive perturbation frequency MPPT algorithm, the calculation of three parameters , namely , maximum value of duty cycle (Dmax),minimum value of duty cycle (Dmin) and scaling factor (C) are very crucial. The value of Dmin and C are calculated as per the following equations respectively.

$$[I(D + \Delta D_{min}) - I(D)].G \geq V/(2N) \quad (1)$$

where, G= gain of current sensor which is equal to 1 in this dissertation.

V= voltage of the PV array.

N= number of bit of the controller used, in case , of hardware.

$$C = \Delta D_{max} \Big/ \left(\left| \frac{dI}{dD} \right|_{\Delta D_{max}} \right) \quad (2)$$

where, dI/dD= change in current as a function of duty cycle.
Dmax= 5 times of Dmin
With the initial value of Dmax , Dmin and Dinitial , given in the table 5.1, a program is embedded into the MPPT controller , which automatically record and save the values of PV current and duty cycle D.

Table 5.1

Dmax	Dmin	Dinitial	ΔD
0.9000	0.2000	0.2000	0.0005

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The code in the model file is run with the value of D from 0.2 to 0.9 of maximum value of D which is 1.The simulation is run for 1 second. The simulation gives 10,000 values of I corresponding to values of D. The first few values of I are negative, due to the irradiation graph and fluctuation. So we calculation of C because the values of I repeats itself as shown in the figure 5.2

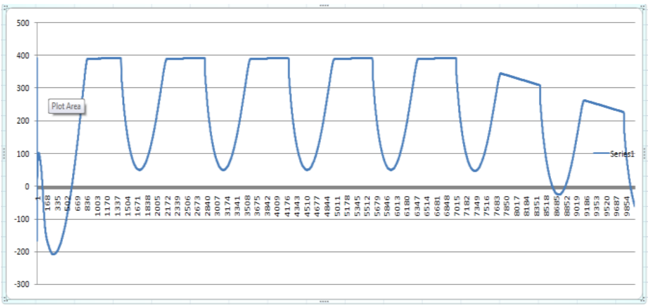

Figure 5.2 Sweep of power duty cycle versus current

Now we will pick one cycle of D in which the value rises from 0.2 to 0.9 as shown in figure 5.3 and will take the corresponding values of I to create a graph. We do this to know how this system's duty cycle and current are related to each other.

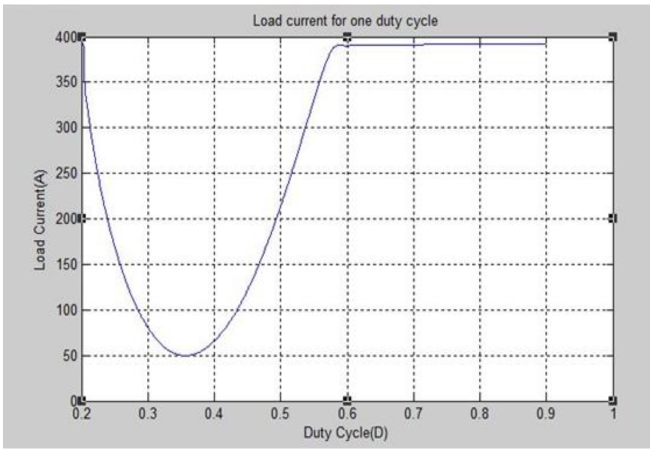

Figure 5.3 load current for one duty cycle.

will ignore the initial data for D=.2 to D=.9.Again the D starts from .2 and increases by .005 up to 0.9.We can take any such section mentioned above for our consideration and

The portion we will take, that is far from maximum power point in the region , for D =.40000 to D=.4025.When we run this model , the values of delta Dmin and C are calculated, as the purpose of this file, and are printed to the command prompt. We need a persistent storage to use this data, which contains the value of C and value of Delta Dmin correspondingly. Every time we run this model file, these data are calculated and refreshed according to the given parameters in the code. This model file is run only for the calculation of the parameters. Hence can be used for different parameters of the PV system.

After the calculation of the parameters, required for the" Adaptive Step Size With Adaptive Perturbation Frequency" algorithm, we can easily run the Adaptive Step Size With Adaptive Perturbation Frequency algorithm. The flow chart of the "Adaptive Step Size With Adaptive Perturbation Frequency "algorithm is shown in figure 5.4.

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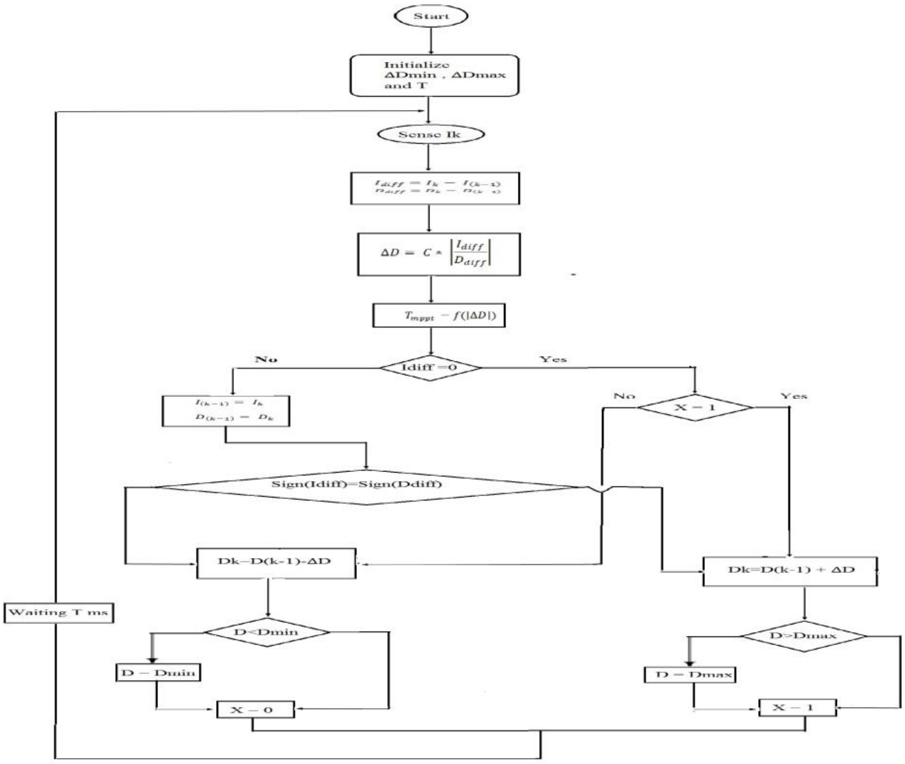

Figure 5.4 Adaptive step sizes with adaptive perturbation frequency MPPT algorithm flowchart.

The algorithm initializes and senses the parameters which are calculated above and then check for the signs of Idiff and Ddiff. If the signs are same, the value of duty cycle is incremented by D and a variable is set to 1 in order to remember the last perturbation direction of duty cylcle.When the signs of Idiff and Ddiff are opposite , the value of duty cycle is incremented by D and a variable is set to 0 in order to remember the last perturbation direction of duty cycle. The duty cycle value is always compared and limited to a minimum vale Dmin and a maximum value Dmax. The programming of the "Adaptive Step Size with Adaptive Perturbation Frequency "algorithm is given in appendix A.

The program was saturating in 2 conditions,

1) When Idiff and Ddiff have the same sign: In such condition when Idiff is NOT equal to zero, and when the value of D is Equal to Dmax, in such case the algorithm asks to assign the value of D to Dprev and increase the value of D by D = Dprev + deltaD. By doing so we are making Dprev =D but as D is already equal to Dmax, any increment in D will not be reflected. So practically now Dprev and D are equal. In next iteration, Ddiff = D-Dprev will not be zero , which saturates the program as no code section is there to handle this situation.
2) When Idiff and Ddiff have different signs:Same case arises when the value of D is Dmin, and the signs of Ddiff and Idiff are opposite. The algorithm assigns the value of D to Dprev and then attempts to decrement the value of D which will never reflect. In order to avoid these two conditions, two if conditions are introduced in the algorithm which is mentioned in the appendix. The output of the algorithm we have designed is depicted in the figure 5.4.

VI. CONCLUSION

FIXED STEP PERTURB AND OBSERVE MPPT ALGORITHM

The simulation and graphical analysis of 100kW grid connected photovoltaic system (SPR300-EWHT) at varying irradiation level and at STC 25 C by using power based perturb and observe maximum power point tracking algorithm (conventional method with fixed step size) have been done in the form of voltage, current and power as shown in Fig.6.2, Fig.6.3 and Fig.6.4 respectively. The irradiance level changes from 1000W/m to 250 W/ m as shown in figure 6.1.This algorithm tracks both the voltage and current of the PV array so that PV array operates at maximum output power (Pmpp).The simulation is carried out for 3 sec. The following figures show the simulation results of the conventional perturb and observation method. At the beginning, the irradiation is set at G=1000 [W/m2] and at t=0.7 sec, a ramped down from 1000 W/m2 to 250 W/m2 is performed. The output power of the PV varies from 100 KW to 23KW.At 1.5 sec to 2 sec, a ramped up from 250 W/m2 to 1000 W/m2 is performed. The output power of the PV varies from 23KW to 100 KW. The PV array operates at maximum power when there is a variation of the irradiance from t= 0 sec to t = 3 sec. At the beginning, the solar irradiation is set at 1000W/m2. From t=0 sec to t= 0.05 sec, pulses to Boost and VSC converters acts as open circuit, PV voltage is open-circuit voltage. At t=0.05 sec, Boost and VSC converters are de-blocked and MPPT is enabled .Steady state is reached at t=0.25 sec. Resulting PV array output power is 96 Kw whereas maximum power with at 1000 W/m2 irradiance is 100.7 kW.

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At MPP , little oscillation is observed .From t=0.7 sec to t=1.2 sec, sun irradiance is ramped down to 250 W/m2 from 1000 W/m2. Still MPPT continues tracking maximum power. From 1.5 sec to 2.0 sec , it takes too long time in tracking the maximum power Corresponding PV voltage and power are Vmean= 255 V and Pmean=22.6 kW. Note that the MPPT continues tracking maximum power during this fast irradiance change. From t=1.5 sec to 3 sec varying irradiance are applied in order to study the performance of the MPPT controller.

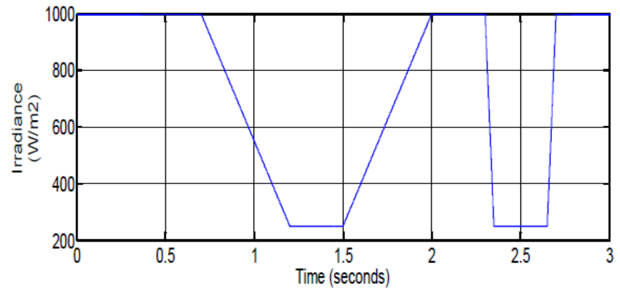
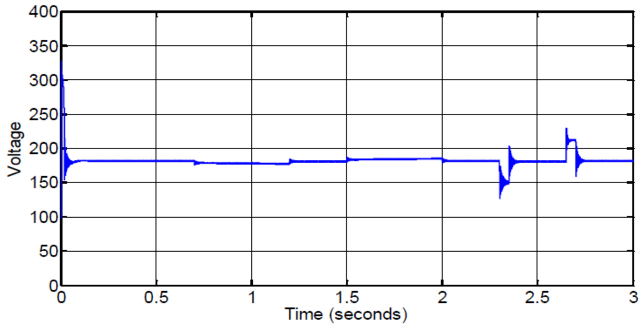


Figure 6.1



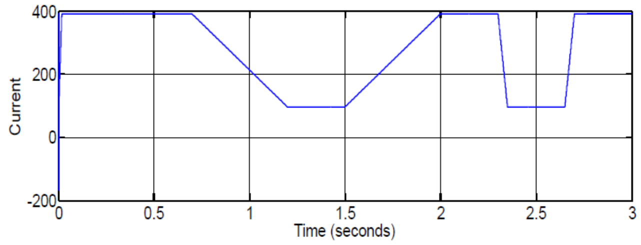


Figure 6.3

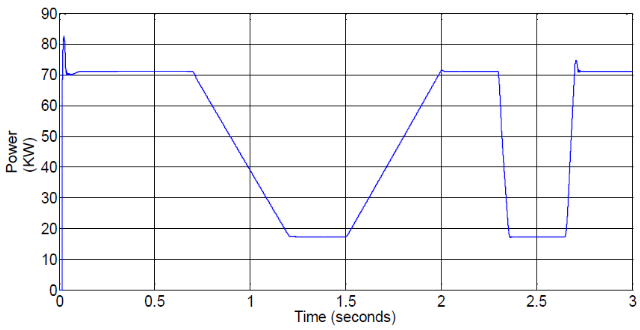


Figure 6.4

FIXED STEP CURRENT BASED ALGORITHM

In fixed current based maximum power point algorithm, maximum power point is achieved by varying current with fixed duty cycle. At the beginning, the solar irradiation is set to be 1000W/m2, and then varies from 1000W/ m2 to 250 W/ m2.The figure shows the varying irradiance graph. At t=0.05 sec, Boost and VSC converters are de-blocked and MPPT is enabled. Steady state is reached at t=0.25 sec. Resulting PV array output power is 71.09 Kw whereas maximum power with at 1000 W/m2 irradiance is 80 kW. Oscillations are observed during the steady state. From t=0.7 sec to t=1.2 sec, sun irradiance is ramped down from 1000 W/m2 to 250 W/m2. MPPT continues tracking maximum power. At t=1.2 sec when irradiance has decreased to 250 W/m2. Note that the MMPT continues tracking maximum power during this fast irradiance change. From 1.5 sec to 2.0 sec , it is faster than the above method in tracking the maximum power point and reaches the steady state soon as compared to the above conventional method but with fixed duty cycle rated power is not achieved. From t=1.5 sec to 3 sec various irradiance changes are applied in order to illustrate the good performance of the MPPT controller. The graphs of power, voltage and current are shown in figure 6.5, 6.6 and 6.7 respectively.

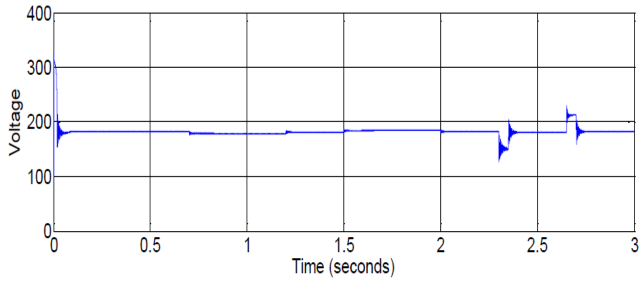


Figure 6.5

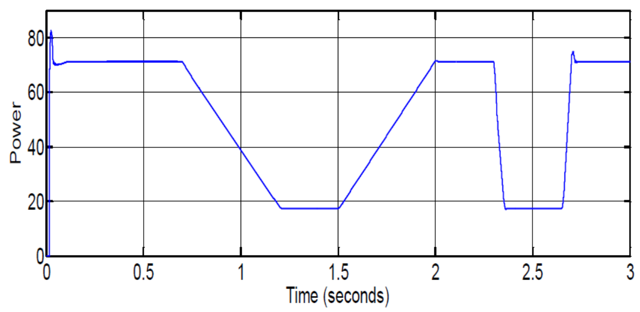
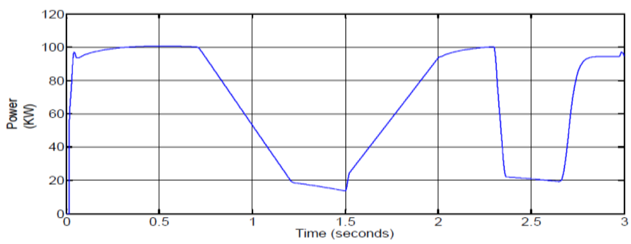


Figure 6.6



LCASF ALGORITHM

The 100kW photovoltaic array (SPR305-EWHT) at 25 C STC and varying irradiation by using current based adaptive step size and perturbation frequency maximum power point tracking algorithm graphical analysis have been done on the basis of power current and duty cycle as shown in graphs.

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The output power, voltage and the load current waveforms are shown in figure 6.8,6.9 and 6.10 respectively.

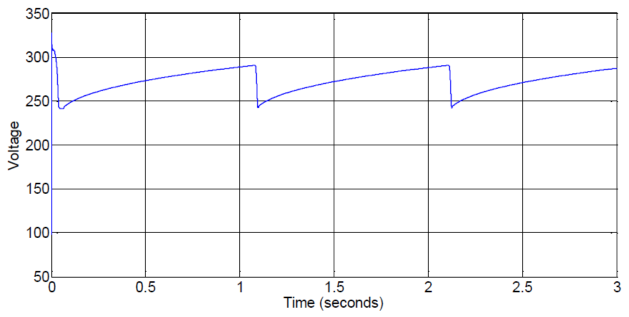

Figure 6.9

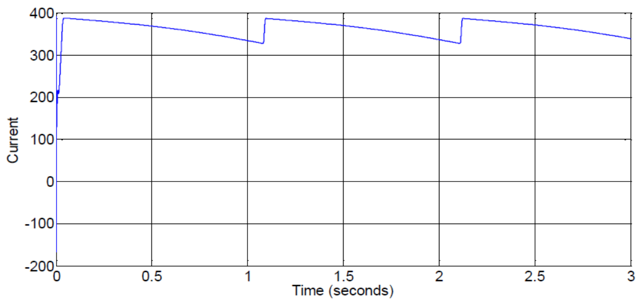

Figure 6.10

The Photovoltaic system was constructed using a 100 kW grid connected photovoltaic array connected in centralized mode. The array composed of 6 parallel strings each containing 5 modules in series to obtain a terminal voltage suitable for grid connection purposes. To simulate the control system and the resulting output currents and voltages of the three phase voltage source inverter, the array was subjected to varying solar irradiation and a temperature of 25° C. The goal of the simulation study in this section was to verify that the proposed algorithm is able to improve the two conditions under which the program was saturating as discussed earlier With the graph we can see that the proposed algorithm adapts to the change in irradiations well and adapts itself to serve at maximum power of 100kW when the irradiation is 1000W/m2. But, it takes longer running time when we implement the adaptive frequency. The hardware implementation of the same algorithm will give more realistic changes in the power as compared to the simulink model. The comparison of the three MPPT techniques in terms of voltage, current and power discussed above are shown in the table below;

Table 6.1 Comparison of the MPPT algorithms

MPPT Algorithms	Voltage (V)	Current (I)	Power (W)
FIXED STEP PERTURB AND OBSERVE MPPT ALGORITHM	275.04	366.03	100.54
FIXED STEP CURRENT BASED ALGORITHM	182.11	390.87	71.09
LCASF ALGORITHM	244.50	386.59	100.4

VII. FUTURE WORK AND CONCLUSIONS OF THE RESEARCH

The research is a continuous work for betterment in the existing and exploration of further research. The study of the photovoltaic system with load current based variable step size and variable perturbation frequency maximum power point controller could also be used with other MPPT algorithms. A laboratory setup should be made to verify the simulation results with the experimental tests. Experimental set up is very important for comparison of variable perturbation frequency with other algorithms as this is not possible from the simulation. In fact, result with adaptive frequency will be accurately seen in the experimental set up. Further studies can still be done with PV system for research purposes .In this dissertation, the study of the photovoltaic system with load current based variable step size and variable perturbation frequency maximum power point controller has been developed. From the theory of the photovoltaic, a mathematic model of the PV has been presented. Then, the photovoltaic system with DC-DC boost converter, maximum power point controller and voltage source converter has been designed. Finally, the system has been simulated in simulink MATLAB First, the simulation of the PV panel is done for the calculation of the parameters that accurately calculates and saves the values of the required parameters for the final simulation. Then, the final simulation of the PV system is done that showed that LCASF algorithm can track the maximum power point of the PV, it always runs at maximum power no matter what the operating condition is. The results showed that the LCASF algorithm delivered efficiency close to 100% in steady state. The results showed that the duty cycle adaptive step size scheme in the proposed MPPT controller yields a trade-off between the convergence speed and tracking efficiency compared to the fixed step size scheme.

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