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Modeling and simulation of maximum power point tracking using buck-boost converter

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Abstract
Photovoltaic Cell (PV) is an environment-friendly source for electric power generation. A photovoltaic module (combination of PV cells) exhibit nonlinear V-I characteristics and maximum power points (MPP), that vary with solar insolation. Also, the PV module offers some impedance which does not match the impedance of the load. So, with the varying maximum power points, and mismatched impedance, load unable to extract maximum power that solar module generates in full day, due to which the overall efficiency of PV system decreases. To extract maximum power from the solar module, it is needed to operate the photovoltaic (PV) system always at the maximum power point (MPP) which is unique for every insolation and match the load impedance with PV module impedance. An intermediate circuit known as MPPT circuit can, therefore, maintain this operating point at MPP and hence ultimately increase the overall efficiency of the system. MPPT device when used with dc-dc converter matches the PV module impedance to the impedance offered by load and maintain the load line of the load at MPP line. This is known as Maximum Power Point Tracking (MPPT). This paper shows a system which provides maximum power to the load at every insolation. We present a simple circuit model of the dc/dc buck-boost converter connected to the photovoltaic systems controlled by incremental conductance algorithm of MPPT. The model has been implemented in PSIM (Powersim).

Keywords: renewable energy, solar cell, MPPT techniques, converter

1. Introduction

In this progressive world, the demand for Electrical energy is increasing day by day. Energy on earth is available in different forms like food, heat, light, electricity, etc. and there is number of energy resource available too. The bulk of the energy is present on this earth which is totally waste in their natural forms but very useful when converted to other forms of electricity. As energy can change its form from one type of energy to other, in the today technology loving era it is converted to one of the most demanded forms of energy that is Electrical energy.

The increase in the market for, "Photovoltaic Powered" devices and solar application-based products is amazingly fast. These applications range from power stations of several megawatts to the ubiquitous solar calculators. MPPT, Maximum Power Point Tracking is the technique of harvesting solar energy. These days the photovoltaic cells are very popular but they are yet not hundred percent efficient. Technology is not much developed which can utilize all the power delivered from the sun. With the help of photovoltaic cells, not even twenty percent of total energy delivered by the sun is utilized to generate electricity. So, to extract maximum power from the sun and utilize it is required to develop that technology which can harness maximum energy delivered by the sun. This can be done by using electronics components. There are a number of ways [9] already present and variety of work is in a process to extract maximum power from the sun. Among them, one of the methods is discussed in this paper i.e. Incremental Conductance method used with buck-boost Converter. This method is very efficient for maximum power extraction from the sun. Lot of work is done over the active solar energy harvesting techniques by using the Photovoltaic cells, which converts the solar energy directly into the Electric Energy. The energy harvesting from the sun is required so that maximum utilization can be taken.

In this paper, a model is designed which will extract the maximum power of photovoltaic module and increases the efficiency of the overall system in terms of power generated by the photovoltaic module. The model will be designed by using dc-dc boost converter with incremental conductance algorithm to achieve maximum power. A report [11] on boost and buck-boost Converters, their operations, characteristics, and performance is explained in it after practical verification. It gives an idea about waveforms, design considerations, and efficiency of these Converters. In [1] an example of the hardware implementation of push-pull Converter with the photovoltaic module is given with the PWM controller. It gives the idea that how the complete MPPT circuit is implemented. It also tells that why push pull Converter should and should not be used in applications. In [2] the Incremental conductance algorithm of MPPT is used with the buck Converter. In [2] the KC85T solar module is used and the simulation model is presented. The simulations and results are analyzed to check the speed and accuracy of the proposed system. It helped in our paper to design the circuit of incremental conductance algorithm. In [3] paper the complete study of buck-boost Converter is done. It gives an idea about how to design a buck-boost Converter and how it will perform. It gives us an idea of using buck-boost Converter and its details with the application of UPS. In [13] various Power electronic devices are present in this book. All the basic calculations of parameters of the buck-boost Converter used in this paper and the operation of ON stage and OFF stage Converter is taken from this book. [4] Present different MPPT algorithms are present which guides about which algorithm should be used and for which application. It also compares different MPPT techniques and gives information about their relative efficiency and usefulness. It also provides the flowchart of all the algorithms so that hardware implementation can become easier. In [8] the buck-boost Converter is shown with four MOSFET and the author have shown the efficiency of four transistor switches buck-boost Converter. The feed-forward network is also added in this and then the transient analysis is done. This paper gives the idea of what is the effect of using more than one switch in buck-boost configuration and how many switches should be used to design a Converter for a particular load. The buck-boost Converter is combined with the incremental conductance algorithm [7] and simulated using the Simulink software. This paper gives a very clear idea about the circuit of buck-boost Converter but the incremental circuit is not completely given here. So this paper helps a lot in the designing of the circuit of the buck-boost Converter. [6] Describes the full day efficiency of the solar module. Basically with the temperature, how efficiency of solar module changes per hour. In this paper, the module was tested for six months and hence the efficiency is shown on an hourly basis per day. This paper gives me an idea about the variations of solar insolation per day and on an hourly basis. It gives an idea about the efficiency of the circuit designed for MPPT. In [9] seven different most popular maximum power point algorithms are described. This paper also shows the flow charts of those different MPPT algorithms. This paper helped a lot in comparing the different MPPT algorithms with each other and in deciding that which MPPT technique is better for a particular load. In [5] the effects of solar insolation over the solar panel are determined. How the characteristics will be varied at a particular point and how the output of the Solar panel is changed is described in the paper completely. This paper helps me analyzing the maximum power of the module in the simulation software while changing the insolation. Analyzing the change in maximum power [33-38] is correct or not, and software used in the paper is working properly or not.

2. Problem Formulation

In present time when all the energy resources [32] are on the verge of extinction, humans are gathering sources which will never extinct. One of them is solar energy. With the Photovoltaic cell, the solar energy can be utilized as electrical energy. But the main problem with the use of solar cell or solar module is its cost. The solar modules are very costly. And if with this high-cost people are not able to utilize hundred percent of the module capacity, then it is a huge loss economically as well as technically. That is why in this field of solar energy harvesting, a lot of work is done and in progress also, so that maximum amount of power or energy can be utilized. A similar problem is faced by the solar module.

The solar module has its own internal impedance and electrical characteristics load cannot extract the maximum power from it as load also have its own characteristics which are different from the solar module. So, we need to design a circuit which can match the impedance of the source with the load so that maximum power [44-49] can be extracted and solar energy can be utilized to the max. Also, it is required that maximum power can be extracted even at minimum insolation for which different circuits are designed. As per unit price of the electricity is increasing due to the high generation cost [30-31]. Expensive electricity evokes the Electricity theft problem [16-22]. An eco-friendly power generation is required with good power quality [39-41, 43].

3. Proposed Methodology

Extraction of maximum power from the solar module at every insolation is known as maximum power point tracking. There are a number of ways to design the algorithm to extract maximum power [14, 15, 23 and 25]. But here the Incremental Conductance algorithm of MPPT is used with buck-boost Converters [11]. The choice of the method depends on the time complexity the method takes to track the MPP, implementation cost and the ease of implementation. This algorithm will be used because it is more accurate and fast.

Buck-Boost Converter is used because it can buck as well as boost the voltage levels with the change in the duty cycle accordingly and its efficiency is also high in comparison to other Converters. It also provides the inverted output voltage and also it can be used in a non-inverting way by applying an inverting operational amplifier circuit. The details of the methods used are given in below sections.

In figure 1 the dP/dV shows the slope at the point before and after the maximum power point, which is not equal to zero but, at maximum Power Point, it becomes zero [4].

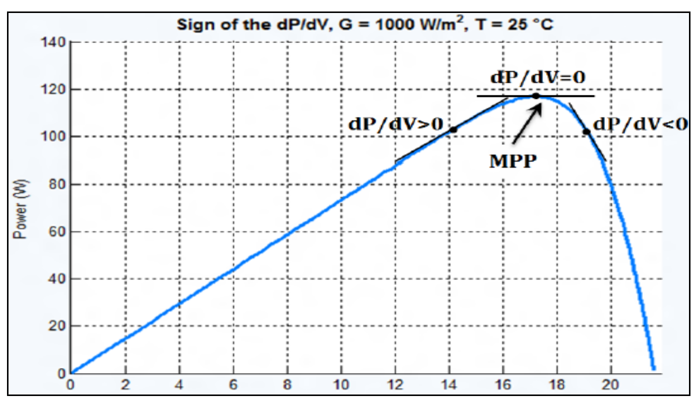

Fig 1: dP/dV curve at different positions on PV curve

Same thing we can analyse in the V-I curve in the terms of dI/dV. In figure 2 it is shown that the dI/dV is less than or greater than –I/V before and after maximum power point and at maximum power point it is equal to –I/V [4].

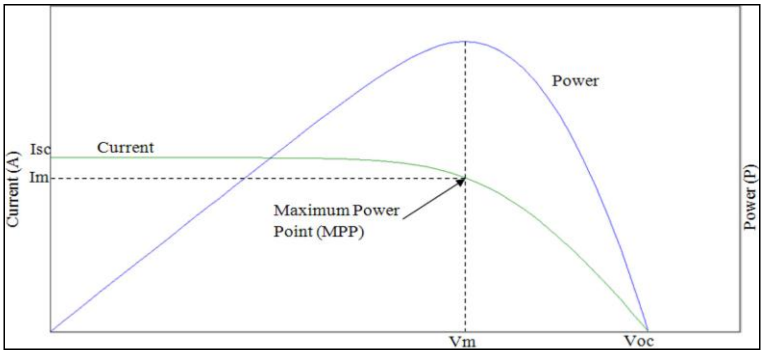

Fig 2: Characteristic curves of a PV module b/w I & V

The algorithm we are using here is based on the conductance that is I/V of the circuit. The voltage and the current are sensed and then their derivative is calculated or changes in present value and the last value is calculated. In the figure 3 flow chart dV and dI is changing in voltage and change in current. When the conditions are shown are satisfied the duty cycle of the Converter will be varied accordingly. It will either increase or decrease to change the output power [12].

3.1 PV System with MPPT

The circuit diagram in figure 5 contains a buck-boost Converter, the circuit of incremental conductance algorithm and PWM with a fixed reference voltage. In the circuit, the components we have used are all ideal and we have neglected the internal resistances of inductors as well as the capacitors. A flowchart in figure 3 is implemented in the circuit to use for decision making purpose. The buck-boost Converter is used for the impedance matching and the incremental conductance method is used for the purpose to decide the location of the operating point of the load.

In figure 4 there is a 60watt solar panel taken and attached to the buck-boost Converter and a 20ohm resistor as load. A load can be varied accordingly but in my work 20ohm load is used. The specifications and the parameters of the buck-boost Converters are calculated according to the formulas given in section 5, also parameters chosen for this are calculated and given in that circuit. In the circuit, the solar panel voltage output is taken by using a capacitor of 30µF. This capacitor maintains the voltage constant. The current is drawn by the load accordingly, but due to the buck-boost Converter in between the voltage and current level at the output changes. The output voltages and current of the module are sensed and supplied to the incremental conductance model, where these values will be processed and will make the decision of increment or decrement of the reference voltage. Simple bidirectional switches are used for the purpose of transferring the decision output of the incremental conductance algorithm to the pulse generator. For pulse generator, we have used a comparator with a reference voltage at the positive input and a triangular voltage at the negative input, when they both are compared then a square wave of a particular duty cycle is generated which is used to control the MOSFET [24,26,27]. Also in the implementation of incremental conductance algorithm, logic gates are used for the decision making purpose. I the software labels are used to connecting the circuit from the same label another side. It shows the connection between two points it prevents the circuit from the messy links and confusions.

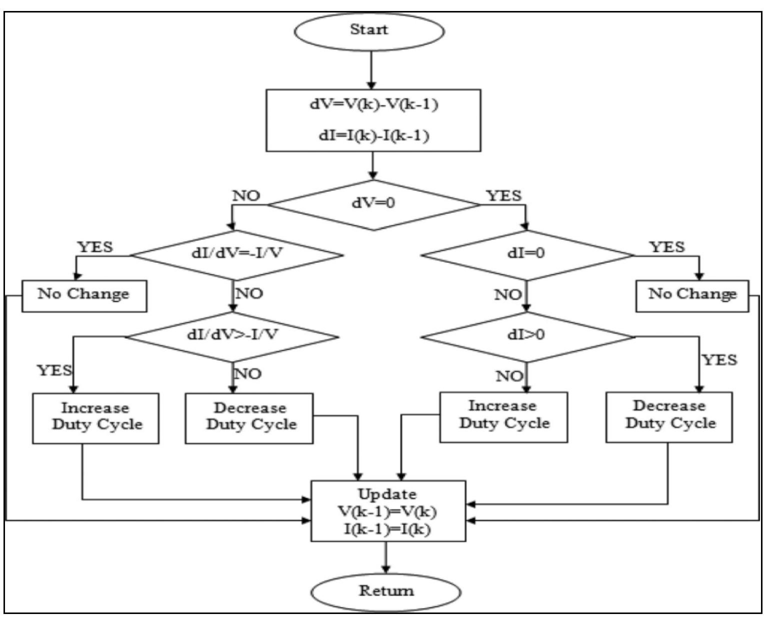

Fig 3: Incremental conductance algorithm results & discussion

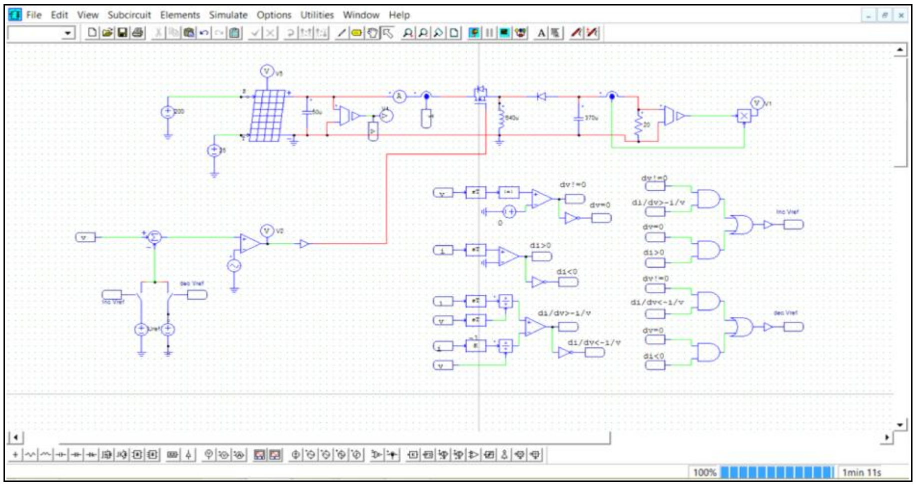

Fig 4: Implementation of circuit on simulator with MPPT

3.2 Pv System Without Mppt

In Figure 5 a circuit is shown without using MPPT technique. The load is directly connected to the Solar panel. Load here is taken to be same as taken with MPPT circuit that is 20 ohm and also the panel of 60watt with same specifications is used because of which maximum power [28, 29] cannot be tracked at every point.Results should be the major findings of your experiment. You have to compare the results with previous studies done in same.

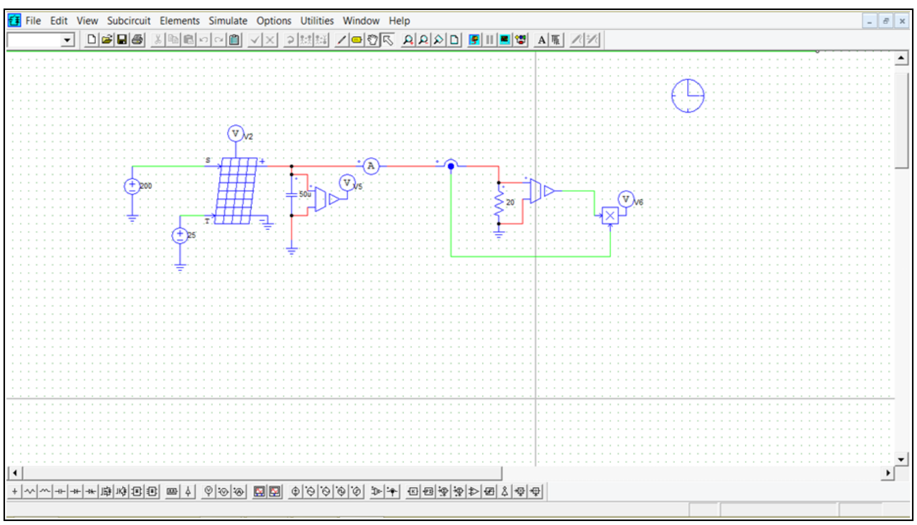

Fig 5: Implementation of circuit on simulator without MPPT

In the similar way as shown in figure 5, the circuit without MPPT is drawn. In the solar panel output a capacitor of 30μF is attached to keep the output voltage of solar panel constant and the load of 20ohms is directly connected to the Solar Panel. A voltage sensor and current sensor is attached to sense the output voltage and current then they are taken to a multiplier which provides the power at the output. Specifications of the buck boost converter used in the circuit are: Capacitor = 370μF, Inductor = 640 μH, Frequency of Converter = 10 kHz, Voltage Ripple = 0.008.

4. Results

The simulation and modeling results are shown and explained. The output of the simulated circuit will be discussed and also the comparison is done between the output powers extracted with MPPT circuit and without MPPT circuit when same insolation is provided. The output waveforms are also shown to verify the results. Table of comparison is formed to show directly the usefulness of the MPPT circuit. The efficiency is also calculated with and without the presence of MPPT circuit and table of comparison is formed to show the direct comparison. Also, the results are compared with the results of similar work done with different types of Converters.

In table 1 the output power at load and the maximum power that can be delivered by the solar panel is shown. A comparison is done between the output power with the MPPT circuit and without MPPT circuit. The Circuit shown in figure 5 and figure 6 are simulated for the purpose and the results shown have come out.

Table 1: Comparison of output power and maximum power of solar module with MPPT and without MPPT

Solar Insolation	Maximum Power of Solar Module	Output Power at load with MPPT	Output Power at load without MPPT
200	11.4	11.3	11
400	23.63	23.4	17
600	35	34.8	20
800	48.5	47.5	20
1000	60	59.8	20

The waveforms at insolation of 200, 600 and 1000 without MPPT and with MPPT is shown in figures 7, 9, 11, 8, 10, 12 respectively. The Unit of insolation is Kw/m2. So it is considered that at 200, 600 and 1000 values of input 200, 600 and 1000 kW/m2 insolation is provided.

In table 2 the efficiencies of the Photovoltaic System are compared with MPPT and without MPPT. In this work, all the components like an inductor, capacitors, MOSFET, diode are considered to be ideal (with no internal resistance). It can be seen that in table 2 of comparison the efficiency comes out to be 99.1-99.6% as all the components are ideal but in the practical model also it will come out in the range of 92-95% which is a very good range in comparison to the efficiency of without MPPT system.

The formula used to calculate efficiency [42] at a particular insolation is:

$$\text{Efficiency} = \frac{\text{Power at Load}}{\text{Maximum Power given by Solar Module}} \qquad (1)$$

The Observed values show that the MPPT circuit enhances the power extraction capability of the load by matching the impedance of the source and the load. Also the incremental conductance algorithm is very useful and accurate.

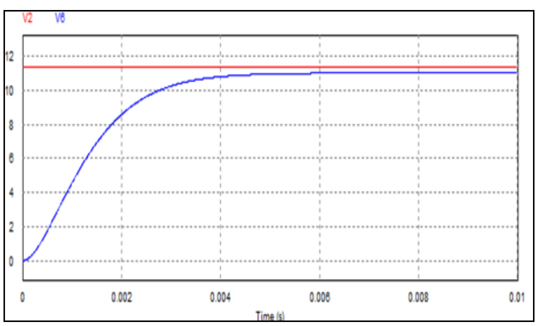

Fig 7: Curve b/w Power at load terminal (V2) and Maximum Power by PV module (V6) at isolation 200 without MPPT.

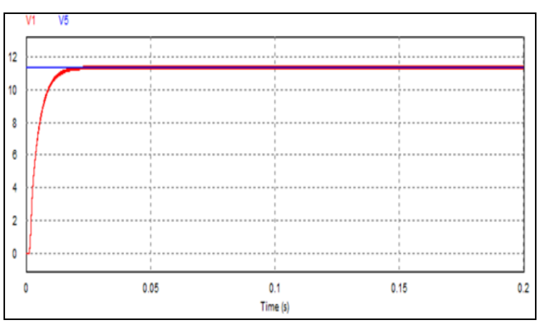

Fig 8: Curve b/w Power at load terminal (V1) and Maximum Power by PV module (V5) at isolation 200 with MPPT.

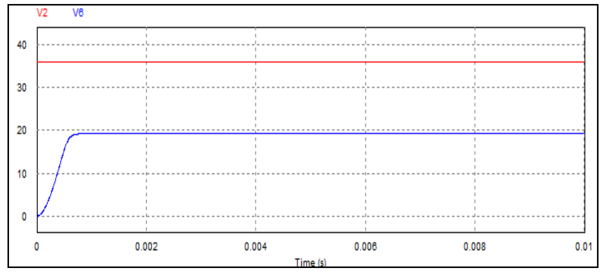

Fig 9: Curve b/w Power at load terminal (V2) and Maximum Power by PV module (V6) at isolation 600 without MPPT.

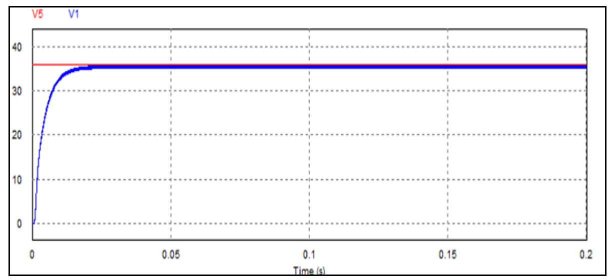

Fig 10: Curve b/w Power at load terminal (V1) and Maximum Power by PV module (V5) at isolation 600 with MPPT.

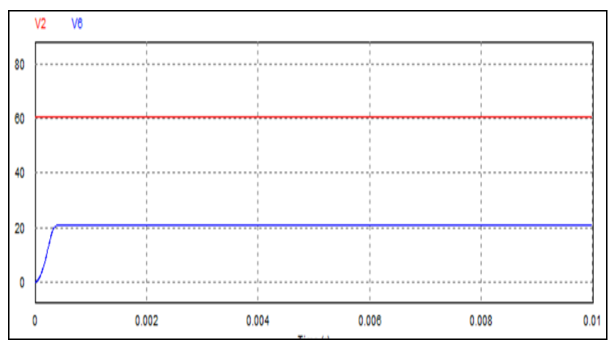

Fig 11: Curve b/w Power at load terminal (V6) and Maximum Power by PV module (V2) at isolation 1000 without MPPT.

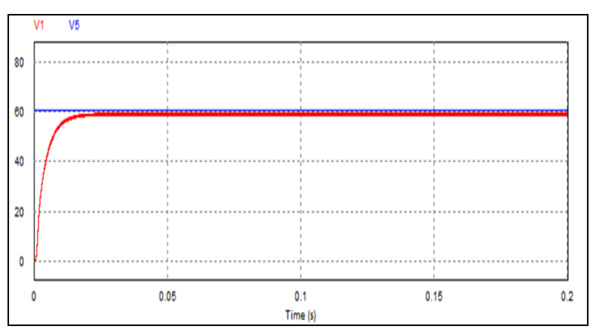

Fig 12: Curve b/w Power at load terminal (V1) and Maximum Power by PV module (V5) at isolation 1000 MPPT.

Table 2: Efficiency with and without MPPT

Solar Insolation	Efficiency with MPPT	Efficiency without MPPT
200	99.1%	96.4%
400	99.1%	72.0%
600	99.4%	33.3%
800	97.9%	33.3%
1000	99.6%	33.3%

8. Conclusions

A Comparison of the Photovoltaic System is done when the Maximum Power Point Tracking Circuit is applied between solar module and load, and without applying that MPPT Circuit or directly connecting Solar Module with the load. Both the circuits are studied for different values of insolation and the results of difference in Power output at load and the maximum power that Solar module can produce is observed in three different cases and hence efficiency is calculated. The circuit contains buck-boost Converter for impedance matching and incremental conductance algorithm is used for maximum power point tracking. It is observed that the power efficiency is increased by applying the MPPT circuit and the load is able to extract maximum power with MPPT. Although due to Converter circuit and other circuitry power loss is increased still this method is very useful and efficient as a whole while dealing with high power rating modules, where we can ignore the circuitry losses. In future any controller can be added like PI, PID, PLC, also Microcontrollers can be used to vary the duty cycle.

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