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Improvement in maximum power generation and service continuity of a PV system

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***Abstract-* The main drawback associated with PV system is inconstant solar radiation and non-continuity of service. This paper proposes methods for enhancing service continuity and increasing the solar radiation on the solar panel. Tilt angle optimization of solar panel and use of mirrors for directing the sunlight increases the net incident radiation. Since solar power output is directly proportional to the total incident radiation, the efficiency of the panel increases. Interrupted supply is another issue associated with PV system. A PV system equipped with a dc-dc converter (act as interface between PV module and load) which is vulnerable to open circuit and short circuit fault is analyzed. The service continuity of such a system is achieved using an additional switch associated with 2 diodes.**

INTRODUCTION

We have been using conventional resources of energy for decades and now their availability is reducing day by day. Besides that conventional resources such as fossil fuels when burnt cause a lot of harmful emissions which lead to greenhouse effect .So we go for renewable energy resources which uses natural and non-depleting resources such sunlight, wind etc. as the input. Renewable energy resources like solar are in wide acceptance today due to a number of its advantages. It is an alternative and relief to the day by day depleting resource like fossil fuel. Since sunlight is the fuel here, fuel availability is abundant and cost is less. Besides this, solar plants produce clean energy i.e.. It does not produce any kind of harmful emissions to the atmosphere. Since Solar is a locally available resource, it can be accessed easily without any tedious steps. Properties like little maintenance and less operating cost add on to the advantages of solar power. Solar panels capture the incident solar radiation and convert it into electricity. Solar energy system works on the principle of photovoltaic effect.

But there are a few disadvantages also associated with solar.

1) Variable solar radiation falling on the panel: This is a major issue leading to unstable output. To overcome this, the incident solar radiation has to be maximized. The methods for the same are discussed in the coming sessions.
2) Non continuity of service: This mainly due to faults in the converter switches of PV system. The remedy for this is discussed.

To maximize the solar output, the input solar radiation has to be maximum. One option for attaining good incident radiation is use of mechanical tracking system. .Tracker is a device with gear mechanism. Solar Panel is mounted on the tracker which traces the path of the sun. This way maximum sunlight is captured by the solar panel. But the main disadvantages associated with tracker are cost, inability to work in bad weather conditions, considerable energy input to overcome inertia of solar panel..Etc. So we go for optimization of tilt angle and use of mirrors for increasing the net solar radiation received by the panel. Optimum tilt angle enhances the incident solar radiation by capturing maximum available sunlight and mirrors direct the sunlight to panel so that panel is exposed to more radiation.

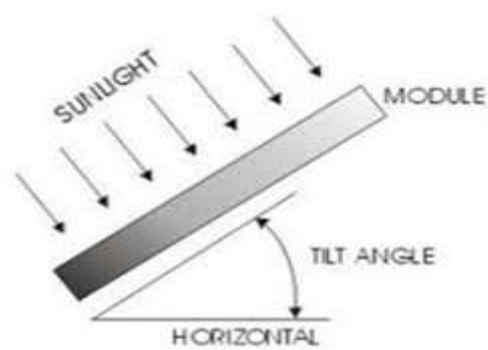


Fig 1. Tilt angle of a solar panel

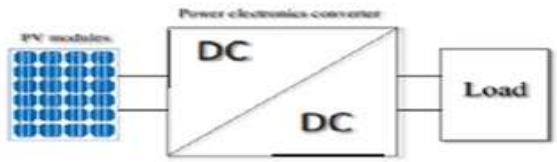


Figure 1.Structure of PV system

The next issue is service discontinuity associated with solar system. PV Systems are now equipped with DC to DC Converter in between solar module and load to match the loads to the power supply. The dc power generated is either lowered (using buck converter) or made high (using boost converter) before giving to the load. The problem of service discontinuity arises in here because the switches in the dc to dc converter cause faults. This fault may be SCF (short circuit fault) or OCF (open circuit fault).In case of SCF, to avoid it we can use a fuse or a switch which will open at the time of fault and disconnect the circuit. In that case also the net result is open circuit fault. So to overcome this fault and ensure service continuity we use 2 steps:

1) Diagnosis of fault: It includes fault detection and location of occurrence of fault.

2) Taking corrective action: This means modification of system structure by actions like adding new components so that the continuity of service is not lost.

Both these modifications are made in the solar energy harvesting system so that output can be maximized

II. MAXIMUM SOLAR INCIDENT RADIATION

A. SOLAR ANGLES:

To know more about how to increase solar radiation incident on solar panel, let us take a look at the basic solar angles. The total incident radiation depends on these solar angles.

i) Tilt angle:

It is the angle between the solar panel and horizontal plane. Performance of a solar PV array is highly influenced by its angle of tilt with the horizontal. Tilt angle change the solar radiation reaching the surface of the PV array. When tilt angle is optimum, incident radiation is maximum. Depend on local climatic condition. Different places will have different optimal tilt angles.

Denoted by β

ii)Declination angle:

It is the angular displacement of sun from the plane of the earth's equator.

Denoted by δ

$$\delta = 23.45 \sin\left(\frac{360(284 + n)}{365}\right)$$

n is number of days starting from 1st of January to the given date.

iii) Hour angle:

Angular displacement of the sun towards east or west of the local meridian. Denoted by ω

$$\omega = \cos^{-1}(-\tan(\delta)\tan(\phi - \beta))$$

$\phi$is the latitude of site

The values of all these angles effect the total incident radiation on solar panel.

B. SOLAR RADIATIONS:

The different solar radiations received by the panel are beam radiation, diffused radiation and reflected radiation.

i) Beam Radiation: It is the radiation that is directly falling to the surface of the solar panel without getting scattered by atmospheric particles. The major part of total radiation is beam radiation.. Optimum tilt angle is selected such that beam radiation is maximized.

$$H_B = (H_g - H_d)R_b$$

WhereH_g is the average daily global beam radiation.

H_d is the average daily diffuse radiation.

$R_b$is the ratio between average daily beam radiation on tilted surface to that on horizontal surface.

$$R_b = \frac{\cos(\phi - \beta)\cos(\delta)\sin(\omega) + \omega_{rad}\sin(\phi - \beta)\sin(\delta)}{\cos(\phi)\cos(\delta)\sin(\omega) + \omega_{rad}\sin(\phi)\sin(\delta)}$$

ii)Diffused Radiation:

It is the radiation that is falling on the solar panel after being scattered by the atmosphere. Its contribution to the total incident radiation on panel is less.

It is given by

$$H_D = R_d H_d$$

where

$$R_d = \frac{(1 + \cos(\beta))}{2}$$

$R_d$is the ratio of average daily diffuse radiation on a tilted surface to that on horizontal surface.

iii)Reflected Radiation:

It is the radiation falling on the panel after being reflected by some reflecting surfaces. The reflecting ability of a surface is represented by its albedo value. Solar panel receives some amount of ground reflected radiation. Since the albedo value of ground is very low, this cannot be taken in to account when we consider the total radiation. But if we use surfaces such as mirrors with good reflecting property, there will be a considerable amount of reflected radiation. Thus we can increase the total amount of radiation falling on the surface of the panel.

Reflected radiation without the use of any mirrors around the solar panel is given by

$H_{R,ground} = H_g \rho \frac{(1-\cos(\beta))}{2}$ →1

ρ is the solar reflectivity of ground.

Reflected radiation on the solar panel after placing mirror around it is given by

$H_R = H_g \rho \frac{(1-\cos(\beta)}{2} + H_g R_{d,mirror} \rho_m \frac{(1-\cos(\alpha+\beta))}{2}$

→2

Here ρ_m is the mirror's solar reflectivity and $R_{d,mirror}$ is the ratio between radiation on tilted surface to that on the horizontal. α is the angle made by mirror with ground.

From equation 1 and 2 it is clear that placing a mirror near the solar panel at an angle so that it can direct sunlight to the panel has contributed to an increase in the total reflected radiation on the panel and thus increase in the net incident radiation and power generated.

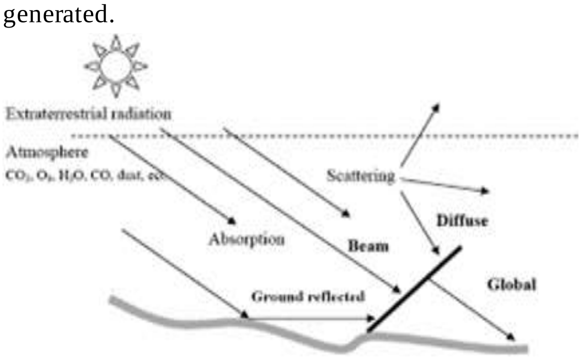


Fig 2.Different types of radiation

C. OBJECTIVE FUNCTION:

Objective function is nothing but the total incident radiation.

$$H_T = H_B + H_D + H_R$$

Without the use of any reflectors, objective function is given by:

$$H_{T,ground} = (H_g - H_d)R_b + H_d \frac{(1+\cos(\beta)}{2} + H_g \rho \frac{(1-\cos(\beta)}{2}$$

After using mirrors the objective function becomes

$$H_T = (H_g - H_b)R_d + H_d \frac{(1+\cos(\beta)}{2} + H_g \rho \frac{(1-\cos(\beta)}{2} + H_g R_{d,mirror} \rho_m \frac{(1-\cos(\alpha+\beta))}{2}$$

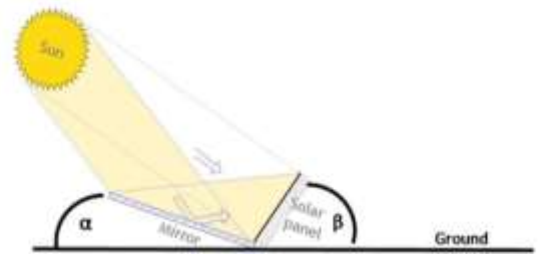


Fig 3. Solar panel with mirror

D. 3 MIRROR CONFIGURATION OF SOLAR PANEL:

Objective function of a solar panel with 3 mirror configuration is given as

Total radiation(H_T)=beam irradiance+ diffused irradiance irradiation from ground reflection+ irradiance from mirror 1 reflection + irradiance from mirror 2 reflection + irradiance from mirror 3 reflection.

$$H_T = (H_g - H_d)R_b + H_d \frac{(1+\cos(\beta))}{2} \\ H_g \rho \frac{(1-\cos(\beta))}{2} \\ + H_g R_{d,mirror1} \rho_m \frac{(1-\cos(\alpha+\beta)}{2} \\ 2 * H_g R_b \rho_m \frac{(1-\cos(\beta))}{2}$$

Here we can observe that the total radiation has increased due to the presence of these 3 mirrors, so mirrors are good option for effective and easy increase in solar output.

TILT ANGLE OPTMISATION:

Optimum tilt angle for a solar panel varies from one place to another depending on its geographical locations.

Here let us analyze the tilt angle versus solar output of a particular country. This can be used as a model or reference graph.

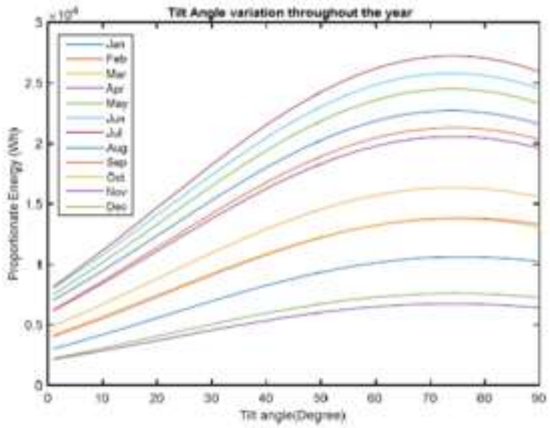


Fig 3.Tilt angle versus output energy curve

Here we can observe that solar output is high when tilt angle is in the range of 70-80. The best fit quadratic equation for this curve is $ax^2 + bx + c$. Differentiating the equation with respect to the x coordinate (tilt angle), we get the value of tilt angle for which the solar output(y coordinate) is maximum.

$$2ax + b = 0$$

$$x = \frac{-b}{2a}$$

For different countries the equation of the graph will be different due to the change in orientation with respect to sun.

But in all case we can find the optimum tilt angle by differentiating the equation of curve with respect to tilt angle and equating to zero.

This tilt angle gives maximum solar output.

III. SERVICE CONTINUITY

Now a days the cost and demand for fossil fuel is instantly increasing ,so this leads to the development of renewable energy .The most commonly used renewable energy is photovoltaic(PV) solar energy .It is clean power source and easily available in nature. When we use PV solar energy continuity of service becomes mandatory. The applications like medical devices, embedded system or sensor network the continuity and uninterrupted supply become mandatory.

In photovoltaic solar energy DC-DC converters become most reason for the failures. The part which is main reason for the failure in DC-DC converter is power semiconductors, mainly the switches. In a survey 34% of failure in power electronic system is due to failure in power semiconductors. The switch failures can be either Short circuit fault(SCF) or an open circuit fault (OCF).In the case of short circuit fault the only way to avoid danger or fault is by cutting the path either by controllable switch in series with path or series fuse to the fault path . In both case, SCF leads to the appearance of open circuit fault (OCF). So in this paper we only consider the case of open circuit fault (OCF).

A. Service continuity

Service continuity in power electronics system allows avoiding the energy transfer cut between the components of the power conversion chain, and the damages to the elements that can result from.

Mainly service continuity includes two steps:

- Fault diagnosis, this step is done to identify the fault and its location. It is the first mandatory steps to perform after the fault occur in the switch. There is different method used for fault diagnosis. The most commonly used method is an OCF and SCF fault diagnosis applied to an non-isolated DC-DC converters it is based on the continues monitoring of inductor current slope[1] ,when there is a sudden change in slop of current we can identify the fault.
- Remedial actions, this step includes the reconfiguration of converter topology and its associated controls. Here may be either new conversion topology or same topology is used same in case of controls either new or old one.

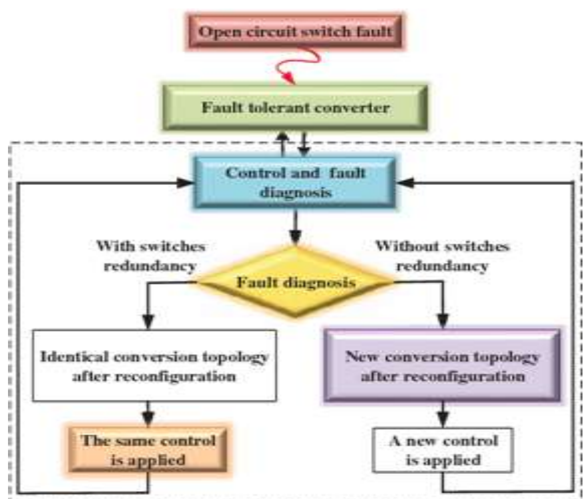


Figure 1.classical service continuity approaches

Classical fault diagnosis and remedial action mainly divided in to two cases (fig 1), first case is with switch redundancy and second one is without switch redundancy. In the first case the operating conversion topology used before and after the remedial action is identical. In this case the control applied is same to the reconfigurable topology before and after the remedial action. In proposed fault tolerant topology a single redundant switch is shared between to DC-DC converters. When a switch fault occur any one of the converters the fault switch will replace by the single redundant switch and thus the operation of fault converter is compromised by shared single redundant switch. On other hand, without redundancy, here no additional components are added after fault detected the normal operation is done after the reconfiguration of both conversion topology and the controls. But without redundancy method is not used for DC-DC converter it is mainly used for AC-DC converter and the researches are going on. However, a degraded method can be achieved without redundancy, were the converter topology remains the same but associated controls is modified [2].

The proposed service continuity approach

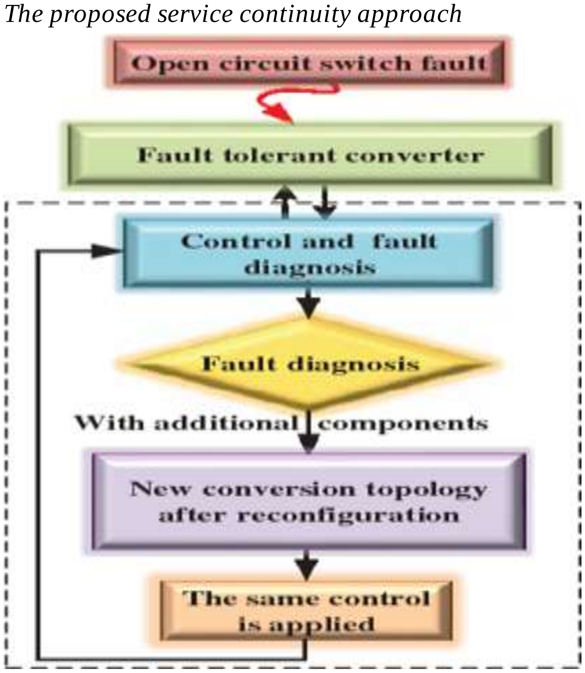


Figure 2: The proposed service continuity approach

In proposed service continuity approach the topology been changed after the reconfiguration but the control is remain unchanged. The proposed method is a combination of classical method (fig 1). New conversion topology is taken from without switch redundancy and the control is from with switch redundancy. In proposed topology the number of redundant switches being reduced, a single switch with two diodes will helps to keep the same operation even after the fault occur. So in proposed method the continuity of service is achieved.

B. CONVENTIONAL SYSTEM

The PV system consisted of a DC-DC converter with energy storage between them (fig 3). In DC-DC converter, Buck converter tracking the maximum power point and Buck-Boost converter to control the output voltage. Both converters can be controlled simultaneously or individually.

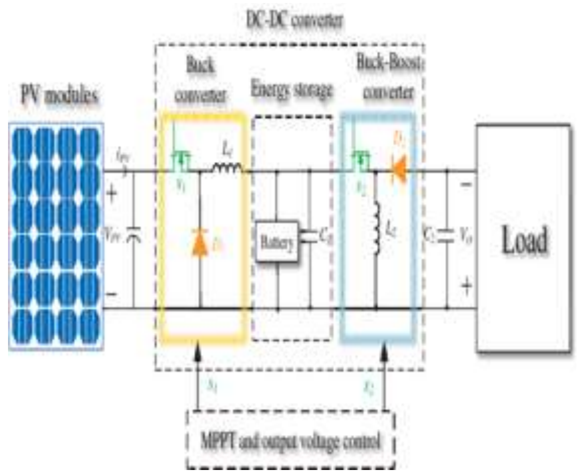


Figure 3: conventional system

To perform service continuity and reduced number redundant switch the solution should share a single switch between switches S1 and S2 (fig 3). For this the circuit is rearranged while keeping the same electrical converter circuit. The conversion is shown in fig 4.

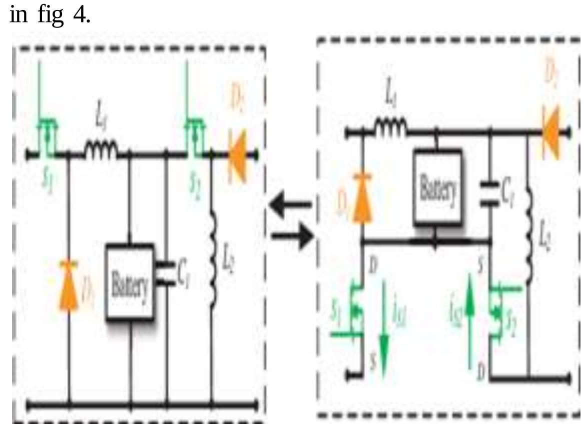


Figure 4: Equivalent electrical converter circuit with common D-S node

Sharing a single switch between S1 and S2 is not possible because the current direction in both switches is opposite (fig 3). But it can be seen that the drain of switch S1 is common to the source of switch S2.so the circuit with common D-S can be replaced with a single switch S associated with two diodes D3 and D4 as shown in fig 5, have the same electrical behavior.

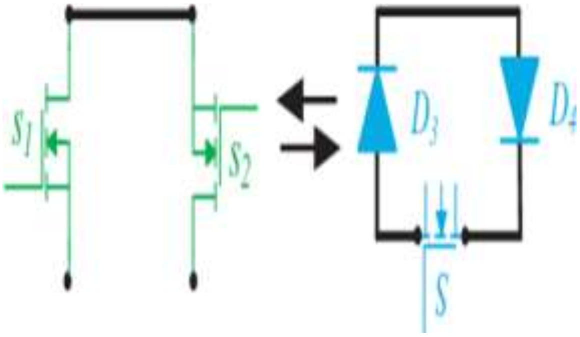


Figure 5: equivalent synchronous switches

C. PROPOSED METHOD

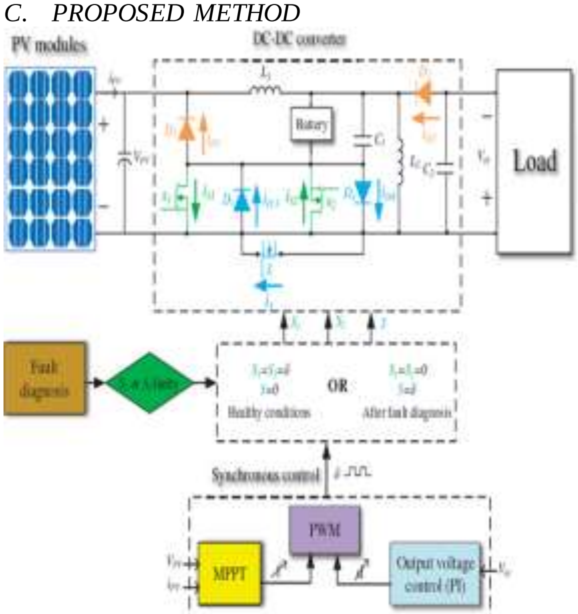


Figure 6: proposed system

In order to ensure the service continuity, we propose a new and original fault tolerant converter (fig 6). This proposed topology is modified circuit of conventional method (fig .3) to which single switch S and two diodes D3 & D4 are added (fig.6). After the detection of open circuit fault (OCF) the new topology will operate in the same function of the system when it working in healthy condition and ensure the normal operation of the system. In healthy conditions, switch S1 and S2 perform normally and driven to perform both the MMPT and output voltage control at same time switch S is disabled and diodes D3 and D4 are reveres biased by the switches S1 and S2. When open circuit fault occur (OCF) or detected at any one switch S1 or S2, both switch become disabled diodes D1 and D2 become reverse biased and switch S become driven and replace the operation of switch S1 and S2, D3 and D4 are also conducting. To be efficient same control is used in both healthy condition and OCF condition for switches S1, S2 and S. As a result, PV system capable of supplying continuous energy to the load even after the OCF occurred. In healthy condition signal ∂ drives switches S1 and S2, S is disabled. In fault condition signal ∂ drives switch S, S1 and S2 are open and disabled (not conducting).

D. *Control of the Proposed Fault-Tolerant Circuit*

As explained previously, the same synchronous control is used for switch S1 and S2 in healthy condition is used in the case of OCF condition also. No change in control before and after the reconfiguration of the conversion topology. Before the failure buck converter perform the MPPT by driving the switch S1 and buck-boost control the output voltage by driving the switch S2. But after the fault occur, both MPPT and output voltage control is driven by switch S.

To ensure the continuity of supply Buck-Boost converter should work in continuous conduction mode (CCM). The transfer function of Buck-Boost converter is given as,

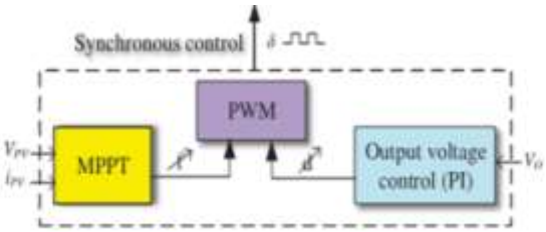
$$M_{buck-boost,CCM} = \frac{V_O}{V_B} = \frac{D}{1-D}$$

From transfer function we can find that, by adjusting the duty cycle D of the buck –boost converter we can control output voltage across the load.

To track the MPPT, Buck converter should work in discontinuous conduction mode (DCM). The transfer function of Buck converter is given as,

$$M_{buck,DCM} = \frac{V_B}{V_{PV}} = \frac{2}{1+\sqrt{1+\frac{8\cdot L_1\cdot f}{D^2\cdot R_{eq}^*}}}$$

MPP of a PV module can be tracked either by adjusting duty cycle D or the frequency F. Here we are using frequency to track the MPP because duty cycle is already taken by Buck-Boot converter. Finally, using the switching frequency F and duty cycle D, the signal ∂ is produced by the pulse width modulation (PWM) block (fig.7).



IV.CONCLUSION

It can be noted that the tilt angle optimization and use of mirrors have increased the incident radiation significantly and service continuity is also ensured by the proposed system.

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