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Pv Fed Adaptive Hystersis Current Controlled Grid Connected Inverter

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Abstract: *PV systems are interfaced to the grid by power electronics converters (DC/DC boost converter and DC/AC inverter). Many of the important characteristics of the PV generation are influenced by the design and performance of the power electronics converters. In this paper, a photovoltaic (PV) system, with maximum power point tracking (MPPT), connected to a three phase grid is presented. For extracting maximum power from photovoltaic system, several Maximum Power Point Tracking algorithms have been developed. These algorithms are applied in DC/DC converter or in DC/AC inverter. In this paper, the MPPT algorithm used is P&O (Perturb and Observe). The connection of PV system on to the grid takes place via current controlled voltage source inverter which also acts as a shunt active filter (SAF). For better utilization of the photovoltaic system, the control strategy applied to SAF is based on I cos Φ theory, which computes the reference compensation currents to be injected by SAF. IcosΦ algorithm provides effective harmonic, reactive power and unbalance compensation. Thus the source is required to supply only the active portion of the load current. Adaptive Hysteresis Band Current Controller (AHBC) determines the switching signals of the APF, which changes the hysteresis band width according to modulation frequency, supply voltage, dc capacitor voltage and the slope reference compensating current wave form.*

I. Introduction

High initial investment and limited life span of PV array makes it necessary for the user to extract maximum power from the PV system. The non linear i-v characteristics of the PV array and the rotation and revolution of the earth around the sun , further necessitates the application of MPPT to the system. In this context, grid connected PV system have become very popular because they do not need battery back up to ensure MPPT. Grid connected PV systems usually employ two power conversion stages. The objective of the paper is to integrate PV system with three phase utility grid via two stage power conversion stage. While the first stage is used to boost the PV array voltage and track the maximum solar power, the second stage inverts this dc power in to high quality ac power. The paper also intends to optimize the switching frequency of grid connected photovoltaic inverter and Total Harmonic Distortion (THD) of the source current through adaptive hysteresis current controller. Perturb & Observe (P & O) algorithm is used for maximum power point tracking and PWM scheme is used for the switching signal generation for the boost converter.

The second power conversion stage is a current controlled Voltage Source Inverter (VSI) which also acts as Shunt Active Power Filter (SAPF). The SAPF working performance is based on the technique used for the generation of reference current. In this paper reference current generation is realized using I cosΦ algorithm. The switching pulse generation for this power stage is realized using Adaptive Hysteresis Band Current Control. The feasibility of the entire system is verified through Mat Lab simulation

II. Highlights Of The Proposed Topology

- A photovoltaic (PV) system, with maximum power point tracking (MPPT), connected to a three phase grid is introduced.
- The connection of photovoltaic system to the grid takes place in two stages-a DC/DC Buck Converter and a current controlled voltage source inverter (VSI).
- Maximum power point tracking algorithms used is Perturb & Observe (P &O) algorithm, which is applied to the buck converter.
- The control strategy for the inverter is based on I cos φ algorithm(used for the generation of reference compensating current)
- Adaptive hysteresis band current controller(variable hysteresis band) is used for switching pulse generation in current controlled VSI

III. Block Diagram

The fig.1 shows the block diagram of PV fed adaptive hysteresis current controlled grid connected inverter. Voltage source inverter based three phase grid connected inverter with control circuit is discussed in this paper. It also acts as a Shunt Active Power Filter (SAPF) and is connected in parallel with the harmonics producing load at the Point of Common Coupling (PCC). SAPF generates a current equal and opposite to that of the harmonic current drawn by the load and injects it at the PCC, making the source current sinusoidal.Calculation of load current harmonics decides the characteristics of harmonics compensation. Current wave form for cancelling harmonics is achieved with Voltage Source Inverter (VSI) and interfacing inductor. Inductor provides smoothening and isolation of high frequency components. Desired current wave form or actual filter current is obtained by controlling te switching of Insulated Gate Bipolar (IGBT) switches in the inverter. Control of wave shape is limited by switching frequency of inverter and available driving voltage across interfacing inductors

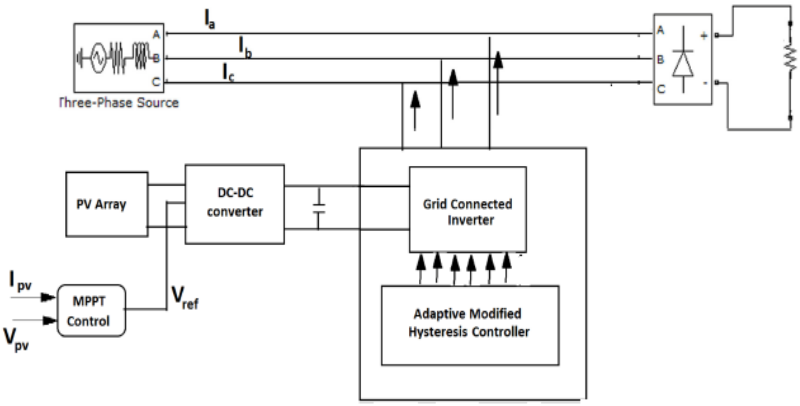

Fig. 1. Block diagram of PV fed adaptive hysteresis current controlled grid connected inverter

IV. Shunt Active Filter Using I Cos Algorithm

The control strategy employed is I Cos Phi algorithm. The control algorithm for an SAF computes the reference compensation currents to be injected by the active filter (AF). The choice of the control algorithm therefore decides the accuracy and response time of the filter. The calculation steps involved in the control technique have to be minimal to make the control circuit compact. The shunt AF is expected to provide compensation for the harmonic and reactive portion of the three-phase load current, and for any imbalance in the three-phase load currents. This ensures that the balanced current will be drawn from the mains which will be purely sinusoidal and in phase with the mains voltage. So the mains is required to supply only the active portion of the load current (i.e, I cos Φ, where "I" is the amplitude of the fundamental load current and cos Φ is the displacement power factor of the load). So the proposed algorithm is named as "I cos Φ" algorithm. It is capable of providing 1) harmonic, 2) reactive power, and 3) unbalance compensation in conjunction with achieving unity power factor at the source end.

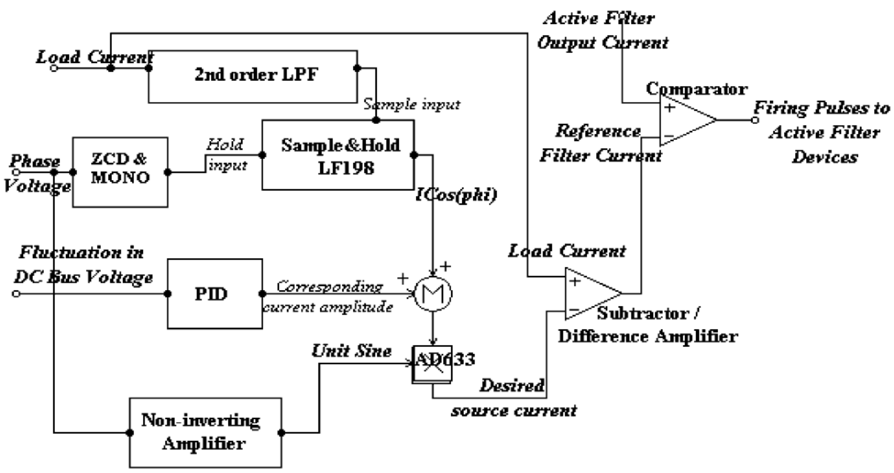

Fig. 2. Realization of I Cos Φ algorithm

V. Hysteresis Controller With Adaptive Band

Increase in energy consumption has led to the development of renewable energy systems. Among the renewable energy sources solar energy is abundant and inexhaustible. DC power from Photo Voltaic (PV) arrays is boosted using DC –DC converters and further converted into AC using inverters before connecting to the grid. Three phase grid connected voltage source inverters interface PV systems with grid. Maximum Power Point Tracking, proper control of power injected into the grid, low harmonic distortion of currents injected into the grid and high power factor are some of the requirements of grid connected inverters. In the present scenario of energy crisis many studies are being done on feasibility of using grid connected inverters fed from photovoltaic arrays, fuel cells etc with active filter functions. Quality of photo voltaic power depends on output current of the inverter. This necessitates efficient current control of grid connected inverters.Several current control techniques has been reported in literature which compare reference and actual filter currents for generation of gating pulses to the solid state switching devices of three phase grid connected inverter.This include Hysteresis control, Sliding mode control, Adaptive control, Fuzzy logic control, Modified Hysteresis control etc. Wide acceptance of Hysteresis band current control method owe to quick current controllability, ease of implementation, fast response and inherent peak current limiting capability. No information about system parameters is needed for this. But variable switching frequency and high switching losses owing to control of all the six switches of the inverter are the major drawbacks of conventional hysteresis controller. Increased inverter operating frequency helps in obtaining better compensating current waveform, but results in increased switching losses. In modified hysteresis controller only 2 switches are controlled at high frequency at any instant of time. This reduces the switching losses to one third of that of conventional controller, where all the six switches are to be controlled. Even though the use of modified hysteresis controller results in reducing the switching loses to one-third, it is insufficient to maintain current THD within the specified limits. To overcome this, pulses to the modified hysteresis controller is generated employing adaptive control by modifying pulses from the conventional hysteresis controller. Problem of variable switching frequency with modified hysteresis controller is also sought out with adaptive control.

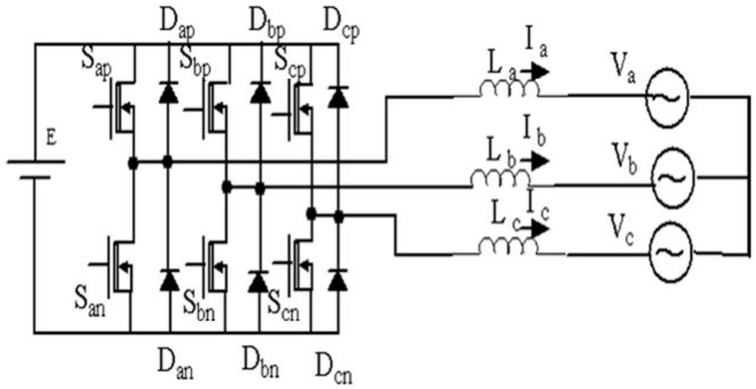

Fig.3. Three phase bridge circuit

In the three wire system given in Fig.3., it is sufficient to control current in only two phases. For compensating harmonic current at source side, harmonic current has to be injected into the grid from the inverter. To inject harmonic current, a generalized switching algorithm is developed based on grid voltage and injected current polarities .Phases having same polarity of voltage is selected for control. This results in low rate of change of inductor current and easier control. The phase voltages are given the notation Ua, Ub and Uc. From the selected phases, controlling switches are selected based on the current polarity. The action of the controlled bridge in each 60° duration of line cycle is explained based on the polarity of source voltage and injected current. From the selected phases, controlling switches are selected based on the current polarityPulses to the modified hysteresis controller are generated using adaptive control by modifying pulses from the conventional hysteresis controller. The output signal from the modified hysteresis controller is used to activate the power switches of the grid connected inverter. The switching logic for an inverter leg is given below

If IL < (ILref –HB), the upper switch is off and lower switch is on for a particular leg.

If IL > (ILref + HB), the upper switch is on and lower switch is off.

ILref is the line reference current and IL is the actual filter current of the respective leg. The fixed hysteresis band technique is very simple, easy to implement with robust current control, has good stability, fast response and inherent ability to control peak current without the need for any information position. These drawbacks result in high current ripples and acoustic noise. about system parameters. But, this method suffers from variable switching frequency, heavy interference, harmonic content around switching side band and irregularity of the modulation pulse To overcome these undesirable drawbacks, an adaptive hysteresis band controlled modified hysteresis controller. Fig.4 shows the pulse width modulated current and voltage waves for phase c. When the current icc- tends to cross the lower hysteresis band at point 1, the upper side IGBT of leg “c” is switched on. When the linearly rising current icc+ touches the upper band at point 2, the lower side IGBT of leg“c” is switched on. The following equations can be written in the switching intervals t1 and t2 from Fig.4.

$$\frac{di_{cc}^{+}}{d_t} = \frac{1}{L}(U_{dc} - U_S) \quad (1)$$

$$\frac{di_{cc}^{-}}{d_t} = -\frac{1}{L}(U_{dc} + U_S) \quad (2)$$

From the geometry of fig. 4, it can be written as

$$\frac{di_{cc}^{+}}{dt}t_1 - \frac{di_c^{ref}}{dt}t_1 = 2HB \quad (3)$$

$$\frac{di_{cc}^{-}}{dt}t_2 - \frac{di_c^{ref}}{dt}t_2 = -2HB \quad (4)$$

$$t_1 + t_2 = t_c = 1/f_c \quad (5)$$

In equation(5), t1 and t2 are the respective switching interval and fc is the switching frequency. Adding equation(3) and equation(4) and substituting equation(5), it can be written as

$$t_1\frac{di_{cc}^{+}}{dt} + t_2\frac{di_{cc}^{-}}{dt} - \frac{1}{f_c}\frac{di_c^{ref}}{dt} = 0 \quad (6)$$

Substracting equation(4) from equation(3)

$$4HB = t_1\frac{di_{cc}^{+}}{dt} - t_2\frac{di_{cc}^{-}}{dt} - (t_1 - t_2)\frac{di_c^{ref}}{dt} \quad (7)$$

Substituting equation(2) in equation(7) gives

$$4HB = (t_1 + t_2)\frac{di_{cc}^{+}}{dt} - (t_1 - t_2)\frac{di_c^{ref}}{dt} \quad (8)$$

Substituting equation(1) and equation(2) in equation(6) and simplifying

$$(t_1 - t_2) = \frac{L}{U_{dc}f_c}\left[\frac{U_s}{L} + m\right] \quad (9)$$

Substituting equation(1), equation(3) and equation(9) in equation(7) gives

$$HB = \left\{\frac{0.25\,U_{DC}}{f_c L}\left[1 - \frac{L^2}{U_{DC}^2}\left(\frac{U_s}{L} + m\right)^2\right]\right\} \quad (10)$$

Where fc is modulation frequency, m=dIrefc/dt is the slope of reference current wave. UDC capacitor voltage of voltage source inverter, L is the interface inductance, Us is the voltage of respective phase.

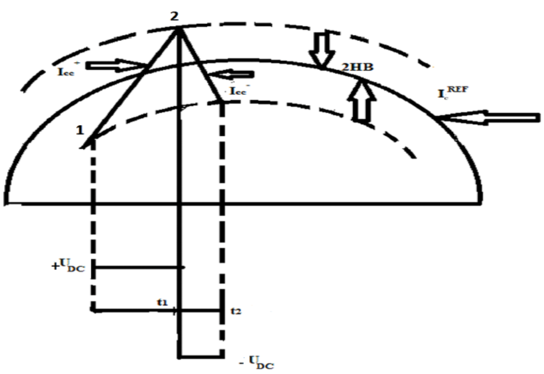

Fig.4. Concept of adaptive control

VI. Switching Algorithm

Let t1, t2, t3, t4 t5, t6 represent the regions 0°-60°, 60°-120°, 120°-180°, 180°-240°, 240°-300°, 300°-360° of the voltage sector respectively [15, 16]. Switches of the grid connected inverter are Sap, San, Sbp, Sbn , Scp and Scn. Let symbols Xa, Xb, Xc represent the polarity of reference currents Iaref, Ibref, Icref respectively. Boolean expressions formulated for enabling signals to switches Scp and Scn in terms of t1, t2, t3, t4, t5, t6 and Xa, Xb, Xc are given below. Cp and Cn are the pulses from the conventional hysteresis controller

$$S_{cp}(c) = (t_1 + t_2 + t_4 + t_5)X_c \quad (11)$$

$$S_{cp}(on) = t_6 . X_c \quad (12)$$

$$S_{cp} = S_{cp}(c).C_p + S_{cp}(on) \quad (13)$$

$$S_{cn}(c) = (t_1 + t_2 + t_4 + t_5)X_c' \quad (14)$$

$$S_{cn}(on) = t_3 X_c' \quad (15)$$

$$S_{cn} = S_{cn}(c) \cdot C_n + S_{cn}(on) \quad (16)$$

VII. Software Implementation And Result

Table1. Specification of simulated PV Module

Peak power(Pm)	**600 W**
Open circuit voltage(Voc)	**200V**
Short circuit current(Isc)	**3.8A**
Operating temperature	**30"C**

The simulation of the proposed system is obtained in MATLAB. Simulation diagram is shown in fig.5.

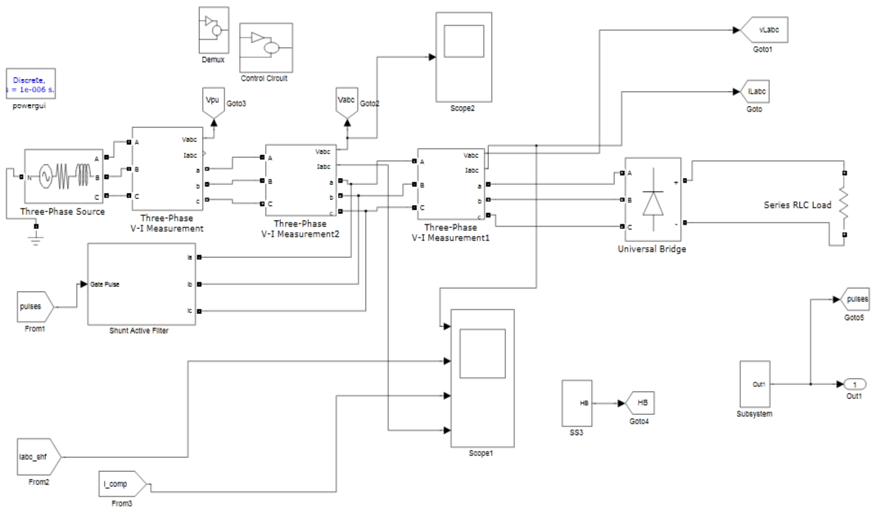

Fig.5. Overall simulation model of the proposed system

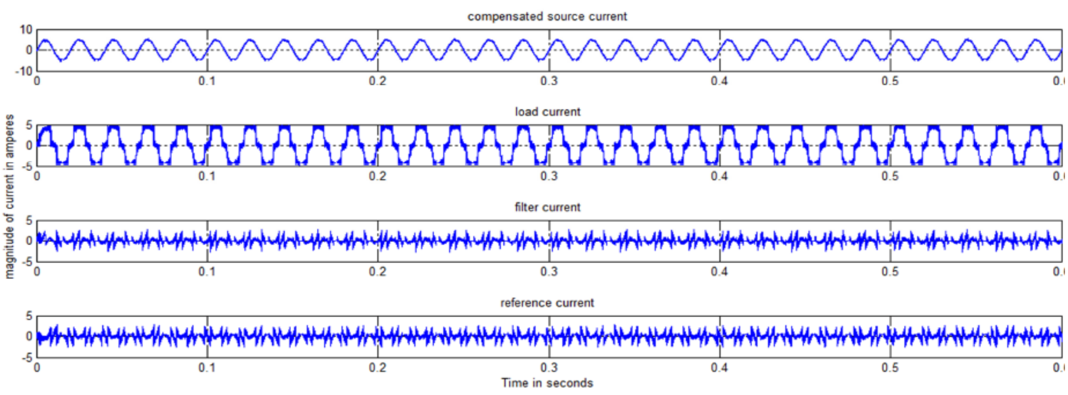

Fig.6. Compensated source current, load current, filter current, reference current

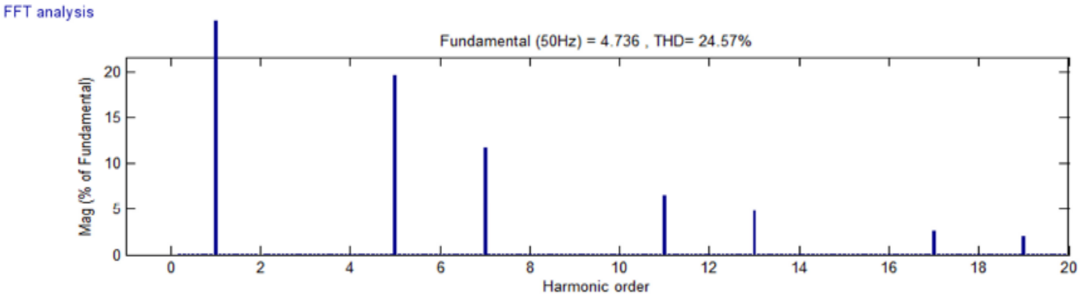

Fig.7. THD of uncompensated source current

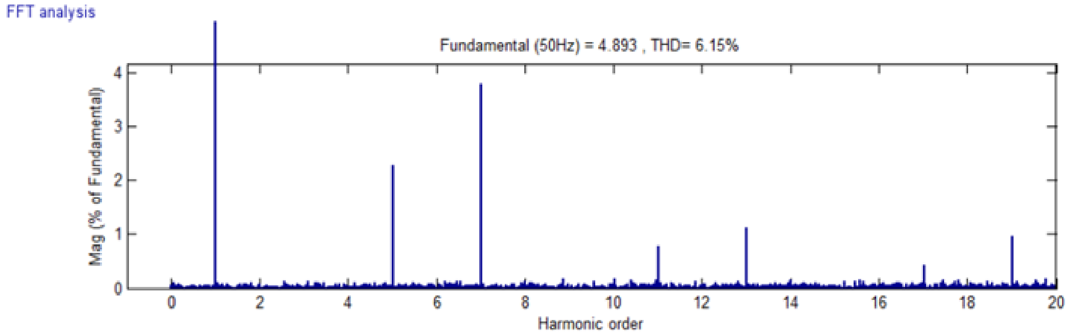

Fig.8. THD of compensated source current with conventional hysteresis controller without adaptive control

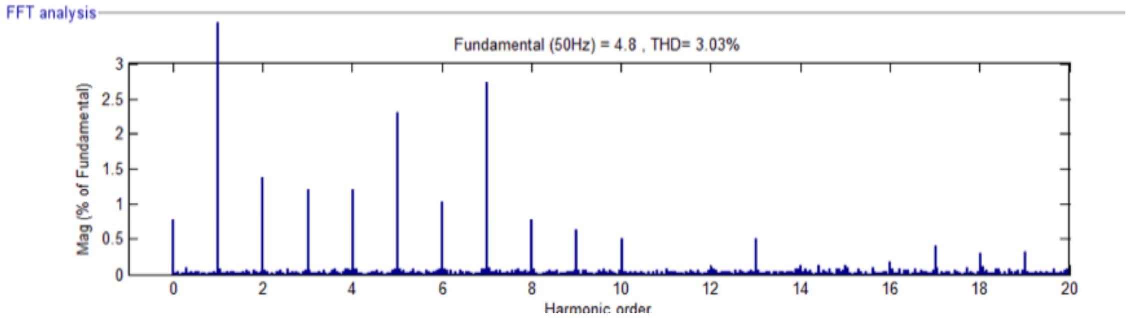

Fig.9. THD of compensated source current with adaptive control

Load current, compensated source current, reference current and filter current are shown in Fig.6. Fig.7.shows that the THD of uncompensated source current is 24.57%.Fig.8.shows the THD of source current using conventional hysteresis controller without adaptive control which is 6.15%.FFT analysis was done on compensated source current and total harmonic distortion was found to be 3.03% as shown in Fig.9. Comparisons of shunt active power filter with conventional hysteresis controller and modified hysteresis controller, with and without adaptive control is shown in Table 1

Table 2: Comparison of conventional and modified hysteresis controller

Current controller used	% THD of supply current	Switching Frequency	Switching Losses
Conventional hysteresis controller	6.15%	Variable	Increased switching losses since all the six switches of the inverter are controlled at high frequency.
Modified hysteresis controller with	3.03%	Nearly constant	Switching losses reduced to one-third since only two switches are controlled at a time at reduced and optimized frequency.

VIII. Conclusion

A three phase source feeding a bridge rectifier with R-L load has been simulated and obtained waveforms for distorted source current. Reference current also has been generated using I cos Φ algorithm and waveforms are obtained through MATLAB Simulation. Minimally switched grid connected photo voltaic inverter with adaptive control, in which switching losses are reduced to one third can be successfully employed for making the switching frequency of the voltage source inverter nearly constant, thereby overcoming the disadvantage of conventional and modified hysteresis controller which has variable switching frequency. Employing adaptive control, the THD of supply current is brought within the 5% limits as specified by the power quality standards.THD is reduced from 24.57% when uncompensated to 3.03% when compensated. Good Dc bus voltage stabilization is also achieved since bus voltage is maintained at 680 volts. Switching frequency of the inverter and THD of source current is optimized with adaptive control.

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