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DFIG Based Wind Power Conversion Systemwith Active and Reactive Power Support

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***Abstract*—The Doubly Fed Induction Generator (DFIG) is the most popular wind power generator. Wind power injection into the grid affects the power quality, stability and voltage regulation. This machine can be operated either in grid connected or standalone mode. A Static Compensator (STATCOM) is used to enhance the reactive power capability of the system. Battery energy storage system (BESS) is integrated to sustain the real power source under fluctuating wind power. A control scheme based on injecting current into the grid using bang-bang controller is presented. Unity power factor is maintained at the grid side. Rotor speed is maintained constant irrespective of the change in wind speed and grid power is maintained constant. This scheme is simulated using MATLAB/SIMULINK.**

***Keywords*—Doubly fed induction generator (DFIG) ; Rotor side converter (RSC); Grid side converter (GSC); Battery energy storage system (BESS)STATic COMpensator (STATCOM); Reactive power compensation.**

I. INTRODUCTION

To have sustainable growth, the energy demand should be met utilizing renewable energy resources. In such system energy conservation is the most important concern. Wind energy is integrated into power system to decrease the environmental impact on conventional plant. For rotor and grid side converters a control strategy is used to improve the low voltage ride through (LVRT) capability of the DFIG WT which helps the DFIG to continue the electricity production even during fault conditions. Here a compensation scheme is used to the grid side controller in order to suppress the DC-link over-voltage during the faults [1].

Presently, doubly fed induction generator (DFIG) is the most widely used wind generator because of its several advantages. First, as the rotor circuit is controlled by a power electronics converter, it is able to both import and export reactive power thus improving power system stability.Second, the machine remains synchronized with the grid while the wind turbine speed varies. A variable speed wind turbine utilizes the available wind resource more efficiently than a fixed speed wind turbine, especially duringlight wind conditions. Another advantage is that only a fraction mechanical power about 25-30% is fed to thegrid through the converter, the rest being fed to grid directly from the stator. Thus the efficiency of the DFIG is increased [2].

Storage-system technologies for intermittent renewable energy sources with simple control scheme like pulsewidth modulation (PWM), space vector modulation (SVM), or bang–bang operation are used [3]. Necessary technical needs and for wind farms, grid co-ordination rules, power system stability, active and reactive power flow, and response of wind farm during grid disturbances are explained [4]. In [5], the effect of static synchronous compensator (STATCOM) for the integration of a large wind farm (WF) into a weak power system is studied.With the help of field SCADA data analysis, a centralized STATCOM is proposed to mitigate voltage fluctuations.

Steady and controlled power from a wind generating station with BESS to level the power fluctuation is done. This scheme has power dispatchability characteristic [6]. Since wind energy is stochastic kind of energy the output may be unstable and the operating point may change. Here an HVDC link is used to provide necessary damping for different wind speeds and disturbances [7].

Energy capacitor system (ECaSS) connected to an electric doublelayercapacitor (EDLC) with power-electronics devices is used to control both active and reactive power simultaneously [8]. Load compensation of DG set connected to distribution feeder is analyzed [9].A STATCOM control scheme for wind energy system with induction generator and BESS is proposed. Here bang-bang controller is used for reactive power compensation and harmonic elimination [10].A two-layer constant power control scheme for a doubly fed induction generator (DFIG) with a supercapacitor is controlled by aby a high-layer wind farm supervisory controller (WFSC) [11]. Active power filter based on optimal voltage vectors and constant switching frequency with hysteresis comparators is used for good current tracking accuracy [12]. Modelling of STATCOM and wind turbine connected to DFIG isexplained in [13].

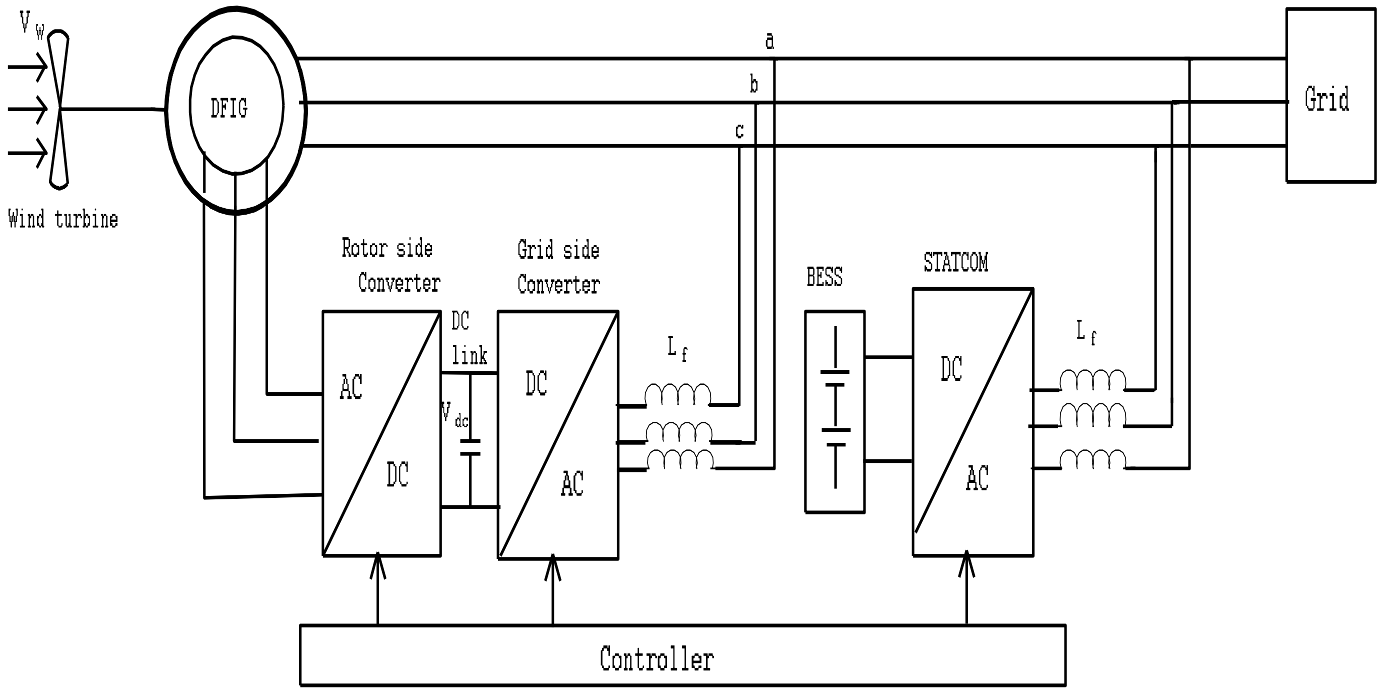


Fig.1.DFIG based wind energy system connected to grid

Section 2 describes the system under consideration. Control part of the circuit is explained in section 3. Section 4 presents the simulation study and the results. Finally section 5 concludes the work.

II. System Description

Fig. 1 shows a schematic of DFIG with rotor side and grid side converters. Rotor side converter is used to maintain the rotor speed constant irrespective of the wind speed and provide reactive power support. Grid side converter is used for maintaining the DC link voltage at a constant value. Here a STATCOM is provided toenhance the reactive power capability and voltage controllability of the DFIG wind turbine system for improving dynamic and steady statestability .BESS is used to provide active power when the supply from DFIG is interrupted and regulate power fluctuations. The control strategies for these converters are implemented in stator flux oriented system. Filters are also connected to the GSC and STATCOM. Synchronous reference frame (SRF) is used to decrease to some extent the complexity of mathematical equations governing the system.

A. Wind Turbine

The output power of a turbine is given by

$$P_m = \frac{1}{2}\rho A_r v_\omega{}^3 C_p(\lambda, \beta) \qquad (1)$$

whereC_P is the power coefficient, ρ is the air density in kilograms per cubic meter, $A_r$is the swept area of rotor blades in square meters, $v_w$is the wind- velocity in m/s, λ is the tip speed ratio, and β is the pitch angle.

B. DFIG

The voltage equations of stator androtor circuits in d-q reference frame at synchronous speed are given by

$$u_{ds} = R_s i_{ds} - \omega_s \psi_{qs} + \frac{1}{\omega_b}\frac{d\psi_{ds}}{dt} \qquad (2)$$

$$u_{qs} = R_s i_{qs} + \omega_s \psi_{ds} + \frac{1}{\omega_b}\frac{d\psi_{qs}}{dt} \qquad (3)$$

$$u_{dr} = R_r i_{dr} - (\omega_s - \omega_r)\psi_{qr} + \frac{1}{\omega_b}\frac{d\psi_{dr}}{dt} \qquad (4)$$

$$u_{qr} = R_r i_{qr} + (\omega_s - \omega_r)\psi_{dr} + \frac{1}{\omega_b}\frac{d\psi_{qr}}{dt} \qquad (5)$$

where $i_s$and $i_r$are the stator and rotor current vectors respectively:$u_s$and u_r are the stator and rotor voltage vectors respectively: ψ_s and ψ_r are the stator and rotor flux vectors respectively: ω_b , ω_s and ω_r are the base, stator and rotor angular frequencies respectively.

C. BESS-STATCOM

BESS stores electrical energy when production exceeds consumption and the stored energy is used when consumption exceeds production. Thus productionneed not be drastically

scaled up and down to meet momentary consumption.Batteries provide a rapid response for either discharging or
charging.They are used for voltage regulation since it is an energy storage element.The battery is connected to STATCOM. BESS can be used to level the power fluctuation by charging and discharging.

STATCOM is a current controlled voltage source inverter. It helps to reduce the reactive and harmonic part of grid current and maintains unity power factor at the grid.

III. Control Strategy

The three controllers in the circuit are modeled for` different purposes. They are for rotor side converter (RSC), grid side converter (GSC) and STATCOM. The controller is based on injecting current into the grid using “bang–bang controller”. SRF theory is used to generate reference current which is based on Park transformation .It is used to generate the source current reference. ‘θ’ the grid synchronizing angle is derived using a PLL(phase locked loop) to generate unity vector template.The three-phase rotor current is transformed from a-b-c stationary system to the direct axis (d) and quadratic axis (q) rotating coordinate.

Hysteresis current controlled technique is used in this controller. The control system variable is kept between the boundaries of the hysteresis area. An input of reference current $i^*_{abc}$and actual current $i_{abc}$are compared to activate the operation of converters in current control mode. The on/off signals for IGBT of converters are obtained from the controller.

If $(i_a) \le (i^*_a - HB/2)$ upper switch of the leg is ON and lower switch is OFF.

If $(i_a) \ge (i^*_a + HB/2)$ upper switch of the leg is OFF and lower switch is ONwhere HB is a hysteresis current band. Similarly switching signals for other phases “b” and “c” can be derived. The switching signals generated here is within a hysteresis band of 0.001. Switching in this narrow hysteresis band increases current quality.

A. Control of RSC

Fig. 2.shows the control circuit of RSC. The three-phase rotor current is transformed from a-b-c stationary system to the direct axis (d) and quadratic axis (q) rotating coordinate (Park’s transformation) and is expressed as

$$\begin{bmatrix} i_{rq} \\ i_{rd} \\ i_0 \end{bmatrix} = \frac{2}{3} \begin{bmatrix} cos\theta & cos(\theta - \frac{2\pi}{3}) & cos(\theta + \frac{2\pi}{3}) \\ sin\theta & \sin(\theta - \frac{2\pi}{3}) & \sin(\theta + \frac{2\pi}{3}) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \begin{bmatrix} i_{ra} \\ i_{rb} \\ i_{rc} \end{bmatrix} \quad (6)$$

Reference currents in abc frame are obtained from a reverse Park’s transformation which is expressed as

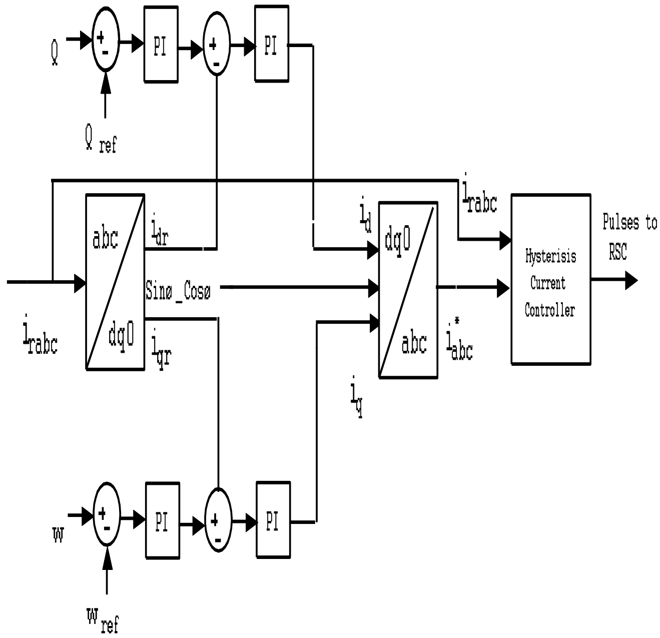


Fig. 2.Control of RSC

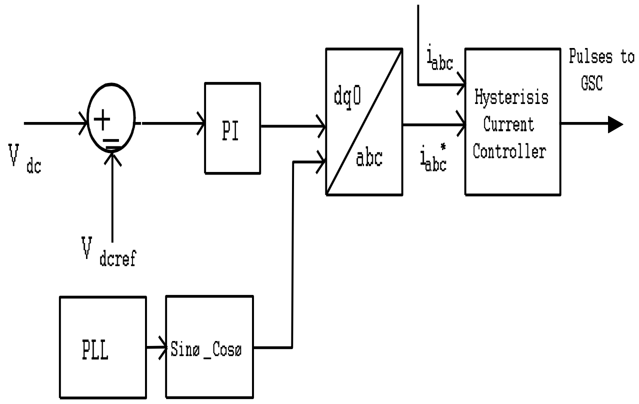


Fig. 3. Control of GSC

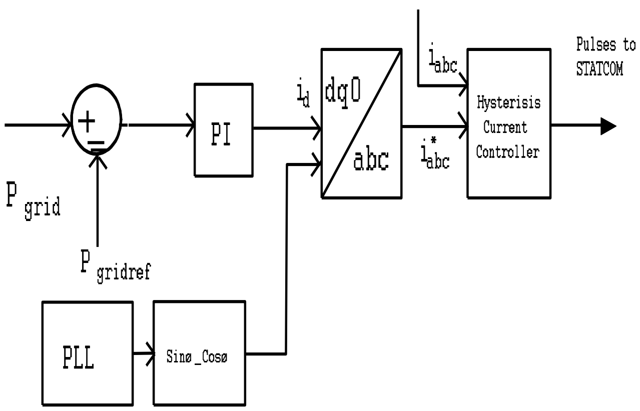


Fig .4. Control of STATCOM

$$\begin{bmatrix} i^*_a \\ i^*_b \\ i^*_c \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta & 1 \\ \cos(\theta - \frac{2\pi}{3}) & \sin(\theta - \frac{2\pi}{3}) & 1 \\ \cos(\theta + \frac{2\pi}{3}) & \sin(\theta + \frac{2\pi}{3}) & 1 \end{bmatrix} \begin{bmatrix} i_q \\ i_d \\ i_0 \end{bmatrix} \quad (7)$$

The actual reactive power ‘Q’ and reactive power reference ‘Q_{ref}’ whichis set as zero is compared and its error is fed to PI controller and then i_d is subtracted from it. This is then fed to PI controller and forms the ‘d’ axis component .Similarly rotor speed ‘ω’ and reference speed ‘ω_{ref} ’ which is set as 1500rpm is given as the ‘q’ axis component. Now dq0 to abc transformation takes place and reference current is generated. This is compared with actual current and is given to the hysteresis controller. The output of this controller is used to provide switching to the RSC thus maintaining the values of reactive power and rotor speed close to the reference values.

B. Control of GSC

Fig. 3 shows the control circuit of GSC which is used to maintain the DC link capacitor voltage constant (V_{DC}). Here the error between V_{DC} which is sensed and DC link voltage reference (V_{DCref})is given to a PI controller. ‘θ’ is obtained from PLL .Then dq0 to abc transformation is done and the actual and reference currents are compared and given to hysteresis controller. Thus switching signals are generated.

C. Control of STATCOM

Fig. 4 shows the control circuit of STATCOM. It is used to provide reactive power compensation. Active power (P) and reference active power (P_{ref}) are compared given to the PI controller and is given as the d axis component.Then dq0 to abc transformation is done and the actual and reference currents are compared and given to hysteresis controller .Thus switching signals are generated..

IV. Simulation Results

Simulation is carried out using MATLAB/Simulink forverifying the performance of the controllers and system response. The parameters used for simulation are given in table 1. DC link voltage across the capacitor is maintained constant and is shown in Fig. 5. In order to study the performance of DFIG under variable wind speed, first the wind speed (Wspeed) is set at 10m/s then varied to 12m/s and 8m/s at 2.5s and 5s respectively. Irrespective of the wind speed rotor speed is maintained at a constant speed of 1500 rpm and is shown in Fig. 6.

Fig. 7(a) shows the active power waveform which is maintained constant at the grid and (b) shows that the reactive power at grid is zero since it is compensated using STATCOM and rotor side converter .The negative value of active power at the grid shows that the grid is receiving power. Unity power factor is maintained at the grid which is shown in Fig. 8. THD of the grid current after compensation is shown in Fig 9.

TABLE I. . SYSTEMSPECIFICATIONS

DFIG	Rated power = 4kW, Voltage =415V Stator resistance =1.405Ω,Rotor resistance =1.395Ω, Speed=1500 rpm F=50Hz
BESS	Nominal voltage=1200V, Internal resistance=10000Ω, capacitance=.675F
Grid voltage	3-phase, 415V, 50Hz
Inductor , L_f	25mH

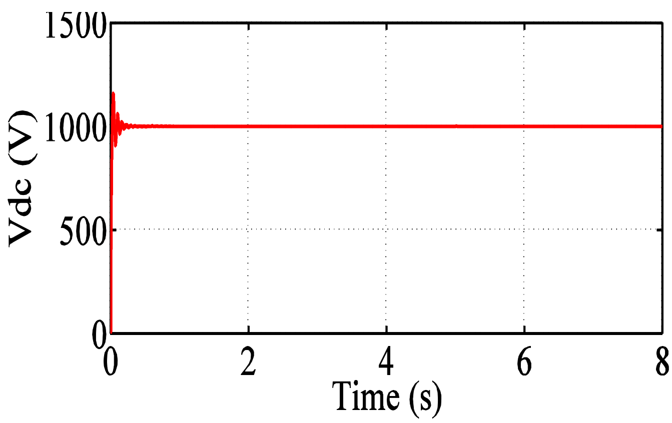
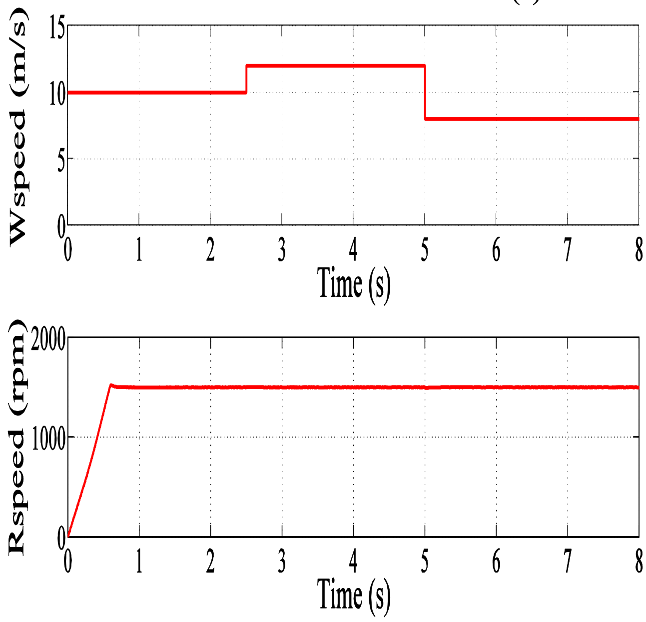


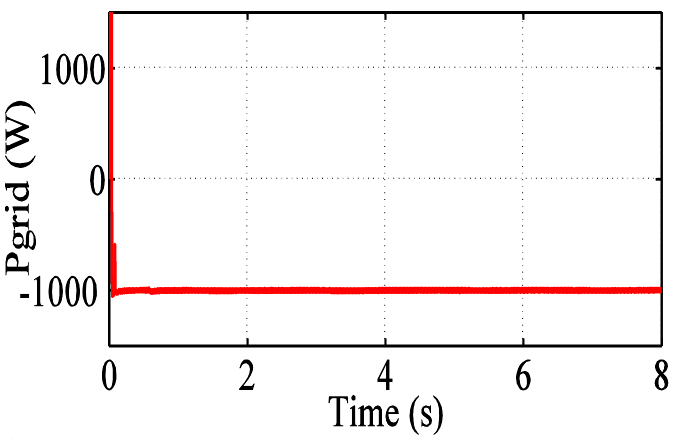
Fig. 5.DC link voltage

(a)

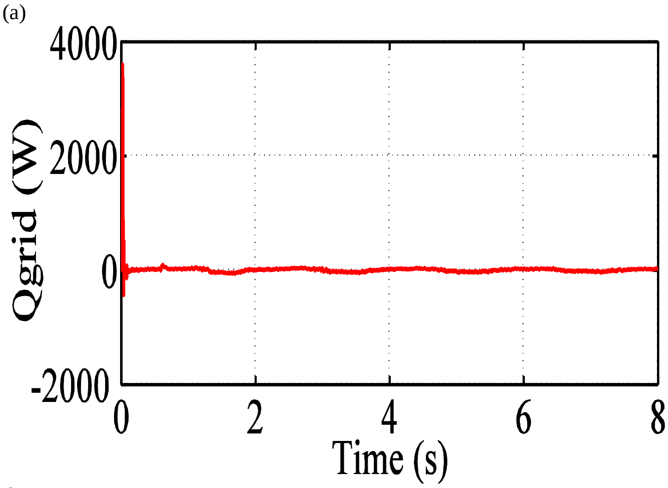


(b)

Fig. 6 (a) Wind speed (b) Rotor speed



(a)



(b)

Fig. 7. (a) Pgrid (b) Qgrid

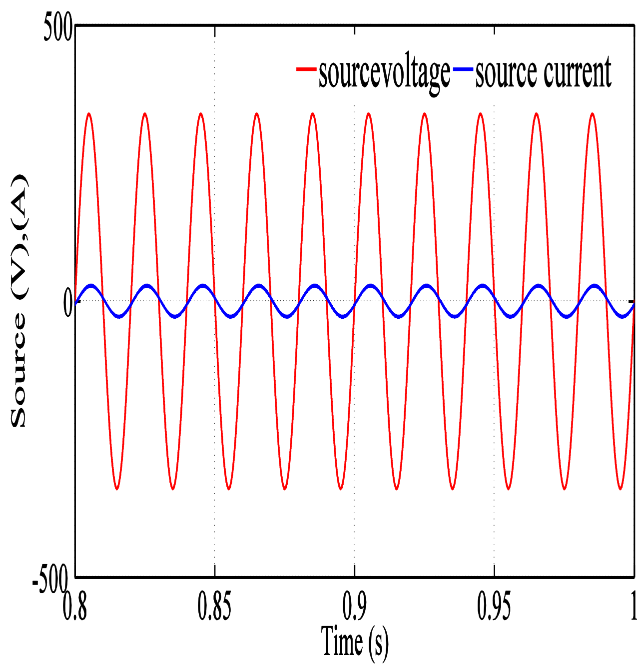


Fig. 8. Voltage and Current at grid

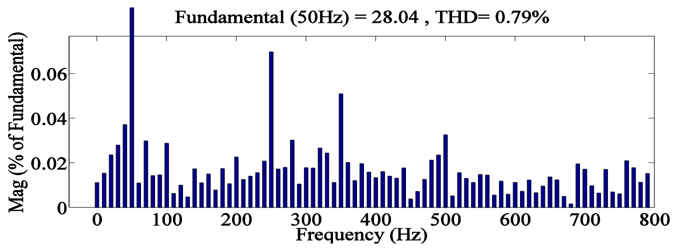


Fig. 9. THD of the grid current aftercompensation

V. Conclusion

This paper presented a DFIG based wind energy system with STATCOM and BESS. STATCOM is used to enhance the reactive power capability and thus the reactive power at grid is compensated and unity power factor is maintained there. Since the rotor speed is constant and BESS is provided, active power supplied to the grid. Thus the controller based on SRF theory is proved to be very effective.

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