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Research Paper

Closed loop controlled boost converter using a pid controller for solar wind power system installation

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Abstract

Deployment of renewable energy resources on distributed energy system has reduced the reliance and transmission losses from the utility grid. It also helps to improve the system stability near the load center. Solar and wind are the two highly utilized green energy resources in present scenario. However, the fluctuations of solar irradiation, temperature, wind velocity are the preeminent issue for this type of systems which affects the efficiency of the solar and wind energy system. It requires the interfacing unit to stabilize the output voltage. The proposed work deals with the close loop boost converter with PID controller, which is used to attain a stabilized voltage despite of parameter changes and load disturbances. Designed system will help to analyze the better stable output voltage with efficient system having minimum fluctuation.

Keywords: *Ssolar PV; wind energy; boost converter; PID controlle;, Matlab.*

1. Introduction

Rapid increase in oil price and environmental concern have drawn huge research interests for non conventional energy power generation. Solar and wind energy systems are two most commonly used resources for the production of electricity in order to minimize the carbon dioxide gas emission [1]. Due to simple installation and cost-effectiveness, solar energy system is more popular than wind energy system. However, for the reliability of the solar system, with the combination of wind is highly preferred [9]. Solar and wind energy system is integrated with power electronic devices like DC-DC converters between source and connected load which helps to utilize the maximum power regardless of climatic conditions [2].

The fundamental topology of DC-DC switching converter is explained with boost converter [3]. However, a wide range of circuit topologies exists from single devices like buck, boost or cuk converters to multi device configuration with complex control and operational arrangement. Boost converter finds huge application in higher power handling applications like hydro electric vehicles, photovoltaics (PV) and charging of batteries, welding, etc. Output power of the PV panel and wind systems varies due to its intermittent parameters like irradiance, temperature, wind velocity etc[17]. Hence, boost converter with close loop system is needed in the system to achieve the robustness in the system. To resolve the problem of variable output voltage, electronic devices are utilized to make the constant output voltage irrespective of intermittent environmental conditions and load variations [4]. To regulate the output voltage generated by solar and wind systems, buck/ boost converter is utilized in the system to adjust the output voltage with smaller/ larger value than the initial voltage.

The load must be provided with a controlled power supply, with consideration of the framework's characteristics like rise time, peak overshoot and settling time [4].

In this regard, PID controller is a more traditionally used controller in various industrial control framework because of its ability of load disturbance rejection. PID control strategy is implemented by a closed loop control technique which provides a control signal for a specific industrial process requirement [5]. It improves the dynamic response and reduce the steady state error. To achieve desired performance tuning of all three separate parameters proportional, derivative and integral designate with P, D and I is the core part of this control algorithm. For selecting the best suited values of P, I and D gains, different tuning techniques are used by the designers like trial and error technique, Zeigler-Nichols technique etc. In trial and error technique, initially integral (K_i) and derivative (K_d) parameters are fixed to zero, then further the value of proportional gain (K_p) is incremented until the system gets oscillations. Next step follows the setting of the integral term to reduce the oscillations or steady state error and after that derivative term to get fast dynamic response [10].

The proposed work includes four sections. Section I deals with the modeling of solar and wind energy sources. Section II presents boost converter which is utilized in the article. Section III comprises the design and implementation of PID controller, whereas Section IV deals with the result and discussions of the proposed model.

2. Modeling of System Input Energy Sources

The proposed system model can be implemented for solar and rectified wind energy sources. Mathematical modeling of the sources is discussed in following subsections.

A. Modeling of Solar Cell

In photovoltaic (PV) solar system, sunlight energy is converted into electrical energy. An ideal PV cell contains a current source with one or more p-n junction semiconductor diode connected in parallel. Whereas, shunt resistance (R_{sh}) and series resistance (R_s) are connected in practice as shown in figure 1. Solar cell is the fundamental unit of a solar array which are grouped to form a module. Modules are further grouped to form a solar array [9].To get more output voltage, series connection is preferred whereas, to achieve large output current cells are connected in parallel [6,12].

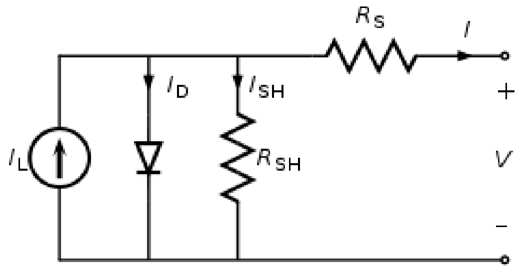

Fig. 1: Single diode equivalent model of a PV Cell

Based on the schematic diagram shown in figure 1, the output current (I) of a PV cell is represented by (1) as follows

$$I = I_L - I_D - I_{SH} \tag{1}$$

Where, I_L indicates current produced by the incident light, I_D represents diode saturation current due to diffusion and I_{SH} denotes shunt resistance current.

Using the Shockley diode equation, expression for current through the diode is given by (2) as below

$$I_D = I_0\left\{\exp\left[\frac{v_D}{\eta V_T}\right]-1\right\} \tag{2}$$

However, thermal voltage or temperature equivalent voltage is given as (3).

$$V_T = \frac{KT}{q} \tag{3}$$

Where, K, q and T represent of Boltzmann constant, electron charge and PV module's operating temperature in Kelvin respectively.The value of K and q are taken as 1.38 $*10^{-23}$ J/K and $1.6*10^{-19}$C respectively. Moreover, characteristic equation of solar cell is expressed in (4) as below

$$I = I_L - I_0\left\{\exp\left[\frac{v_D}{\eta V_T}\right]-1\right\} - \frac{v + IR_S}{R_{SH}} \tag{4}$$

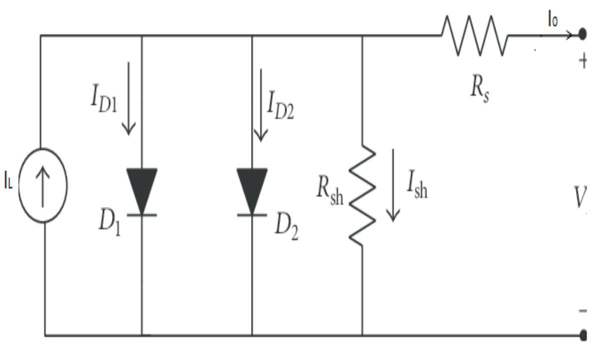

Fig. 2: Double diode equivalent model of a PV cell

Based on the schematic diagram shown in figure 2, current equation can be given as equation (5) as follow

$$I = I_L - I_{D1} - I_{D2} - I_{Sh} \tag{5}$$

Where, I_{D1} = diode saturation current due to saturation and I_{D2} = diode saturation current due to charge recombination. Equation (5) can be transformed as following

$$I = I_L - I_{01}\left\{\exp\left[\frac{v_D}{\eta_1 V_T}\right]-1\right\} - I_{02}\left\{\exp\left[\frac{v_D}{\eta_2 V_T}\right]-1\right\} - \frac{v + IR_s}{R_{Sh}} \tag{6}$$

The double diode model of PV cells is more recommended for better accuracy purpose. Whereas, single diode model eliminates recombination process. Hence, the single diode model is simple and suitable for testing purpose.

B. Modeling of wind system

The wind energy system have two or more blades in which horizontal-axis rotor mechanically coupled to an electrical synchronous generator. The system transforms the kinetic energy (K.E.) of wind into electrical energy which is expressed in (7) [13].

$$\text{K.E.} = \frac{1}{2} m v^2 \tag{7}$$

Where, m indicates the mass of air (kg) which has been further formulated in (8) and v denotes the air velocity (m/s).

$$m = \rho A d \tag{8}$$

In this case, ρ , A and d represent air density (kg/m^3),area swept by the rotor blade (m^2) and distance travelled by the wind (m) respectively. The ideal mechanical power captured by the wind turbine is given by (Pw) [7] in (9) as below

k

$$Pw = \frac{K.E.}{t} = \frac{\frac{1}{2}\rho A v^2 d}{t} = \frac{1}{2}\rho A v^3 \tag{9}$$

But, the actual power depends on the power coefficient C_p (λ,α) of wind turbine, which is the function of pitch angle (α) and the tip speed ratio (λ). C_p is the measure of the efficiency of the entire wind turbine system which is the ratio of true electrical power generated by the wind turbine to the total wind turbine power at specific wind speed. The expression for the tip speed ratio (λ) is expressed [7] in (10) as follows

$$\lambda = \frac{\omega R}{v} \tag{10}$$

Where, ω and R are the turbine angular speed ($rad/\sec$) and radius of turbine (m) respectively.

Therefore, true power extracted by a wind turbine [8] can be given by (11) as

$$P = \frac{1}{2} C_p(\lambda,\alpha)\rho A v^3 \tag{11}$$

Hence, the torque produced by the wind turbine is expressed as,

$$T = P \times \omega = \frac{1}{2} C_p(\lambda,\alpha)\, \rho A R v^2 / \lambda \tag{12}$$

The power coefficient is a nonlinear function varies between 0.4 to 0.6. Theoretically, the maximum value of C_p is 0.59

C. Boost Converter

The DC-DC power converter operates with periodically on and off of an electronic switch like MOSFET, IGBT etc. Output voltage of the boost converter is always greater than the applied input voltage [16]. The schematic diagram of a proposed boost converter is represented in figure 3 [14, 20, 21]. Its operation is based on two modes according to switching condition of the switch.

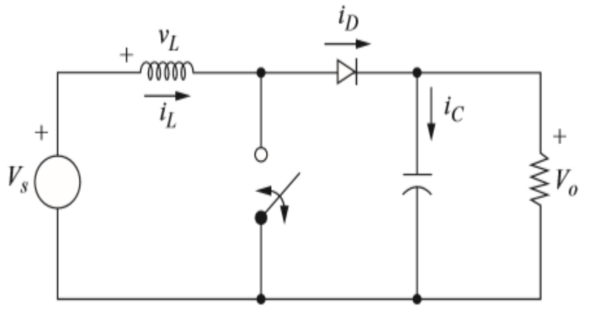

Fig. 3: Schematic diagram of boost converter model

(i) Mode I: Switch is closed

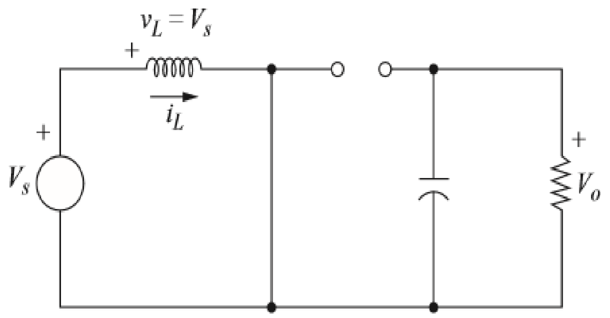

Fig. 4: Equivalent circuit when the switch is closed

In this case, diode becomes reverse biased. Hence, at the load side, no current flows. Only, current flows from source to inductor via switch back to supply. Switch is closed for DT time, where D Is duty ratio of switch and T is switching period.

$$v_L = V_S \tag{13}$$

(ii) Mode II: Switch is open

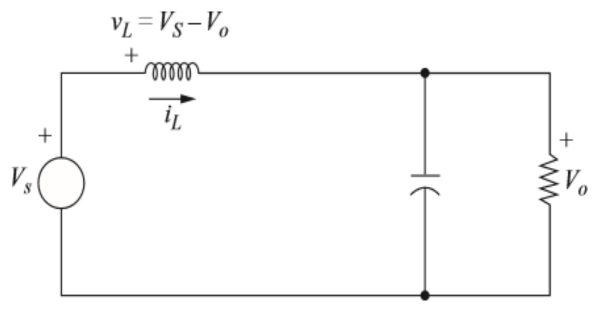

Fig. 5: Equivalent circuit when the switch is open

In this case, the electronic switch opens and diode becomes forward biased because inductor does not a sudden change in current. The witch is open for (1-D)T time. Direction of current remains same as in mode I with completing KVL loop from supply to load (R) through inductor (L).

$$v_L = V_S - V_0 \tag{14}$$

For the periodic operation, the average inductor voltage must be zero

$$V_S(D + 1 - D) - V_0(1 - D) = 0 \tag{15}$$

$$V_0 = \frac{V_S}{1 - D} \tag{16}$$

Above equation 16 represents the output voltage equation of step up converter.

D. PID Controller

Conventional proportional integral derivative (PID) controller is extensively used in process control industrial applications. PID controller involves three different tune parameters, i.e, proportional, integral and derivative [15]. Derivative parameter is not considered for use with only proportional and integral terms as PI control also called proportional plus reset action controller [11].

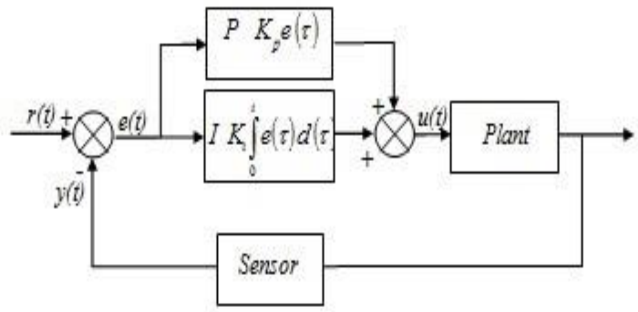

Fig. 6: Block diagram of PI controller

The analytical expression for u(t) of the PI controller is expressed in (17) as

$$u(t) = K_p e(\tau) + K_i \int_0^t e(\tau) d(\tau) \tag{17}$$

Where, r(t)=Reference voltage, y(t)=Actual output voltage, $e(\tau)$=Error signal, K_P=Proportional gain tuning parameter and K_i =Integral gain tuning parameter.

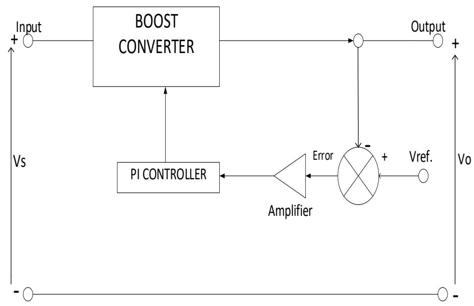

Fig. 7: Block diagram representation of boost converter with PI controller

Figure 7 represents closed loop functional block diagram of step up converter using PI controller. The actual voltage response (Vo) of the boost converter is subtracted with constant set point voltage (Vref.) to form the error signal. The error signal is amplified and processed to the PI controller to reduce the error [18,19]. Moreover, the PI controller generates the control driving gate pulse according to the error signal for varying the switching time of the electronic switch of the boost converter, to produce the constant output voltage (Vo) irrespective of disturbance in the input voltage and load. PI controller parameters K_P and K_i are adjusted to optimize performance and stability of the system to get efficient and accurate control.

3. Simulation Results and Discussion

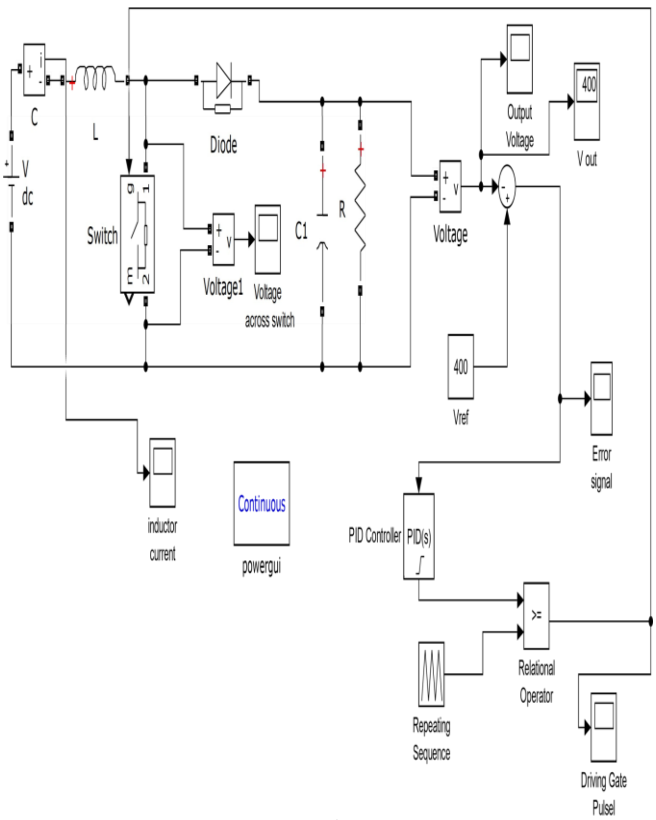

Fig. 8: Simulation model for the proposed system

Boost converter for solar or rectified wind installation system is modelled and simulated in MATLAB. Boost converters parameters are shown in Table I. Proportional, integral and derivative parameters are K_P = 0.00034, K_i =1, K_d = 0 respectively. The proposed model utilizes a PID controller for DC-DC Boost converters in which the derivative parameter is eliminated because it is more sensitive to noise signals and the waveform of output voltage is changing fast with respect to set reference voltage 400 V. For input voltage as 300 V and Load R =200Ω inductor current, driving gate pulse, error signal and output voltage are shown in Fig.9, Fig.10, Fig.11 and Fig.12 respectively. Various simulation results of output voltage are represented in Fig.13, Fig.14 and Fig.15 for different V_{in} and R as shown in Table II.

Table 1: Converter Parameters used in the Simulation

Input Dc Voltage (V_{dc})	300 V
Inductor (L)	25e-3 H
Capacitance (C)	1e-6 F
Load (R)	200 Ω
Duty ratio (D)	0.25
Output Voltage (V_0)	400 V

Table 2: Simulation Results For Different Input Voltages and Load Variations

Input voltage, V_{in}	Load resistance, R	Output voltage, V_o
300 V	200 Ω	400 V
275 V	200 Ω	400.1 V
300 V	250 Ω	399.8 V
275 V	250 Ω	400 V

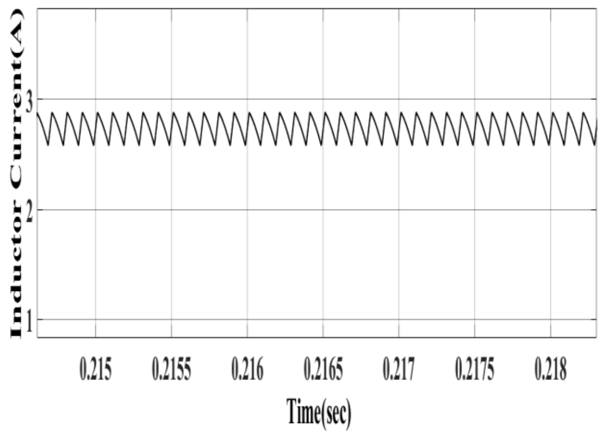

Fig. 9: Inductor current response

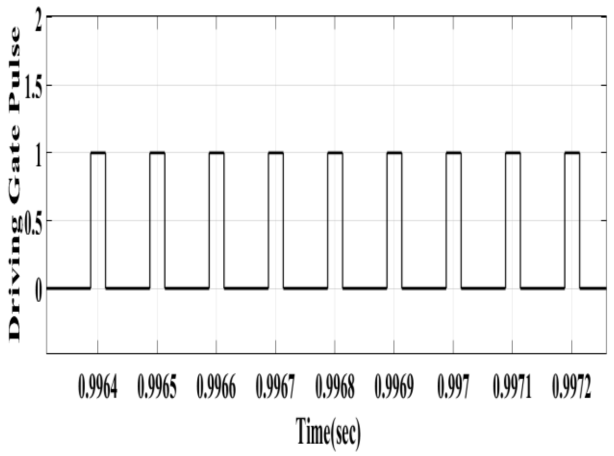

Fig. 10: Driving gate pulse signal

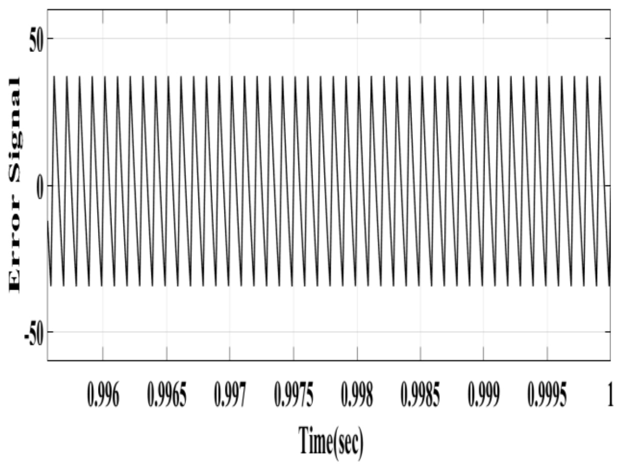

Fig. 11: Error signal of PID controller

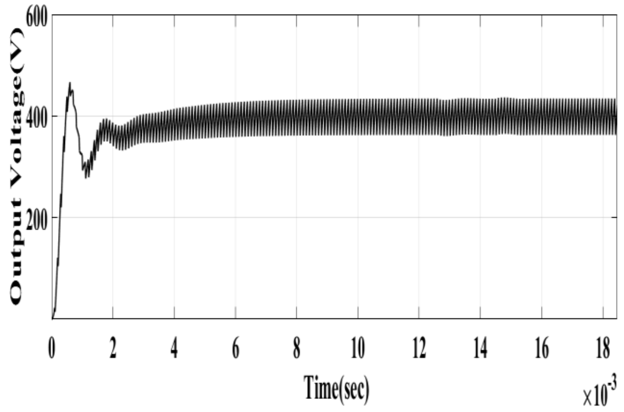

Fig. 12: Output Voltage response at V_{dc} =300 V and R=200Ω

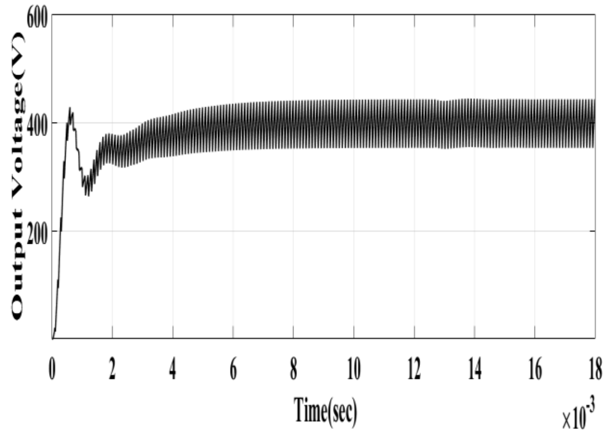

Fig. 13: Output Voltage response at V_{dc} =275 V and R=200Ω

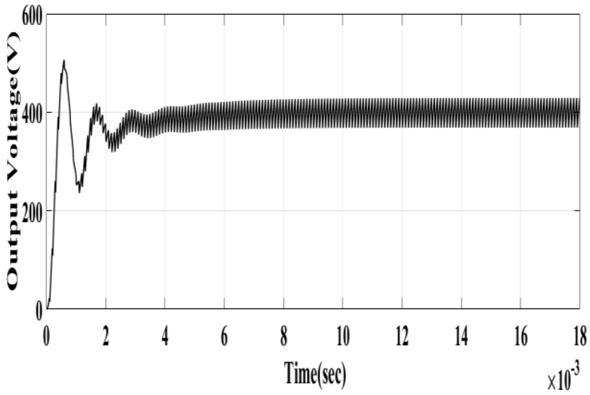

Fig. 14: Output voltage response at V_{dc}=300 and R =250 Ω

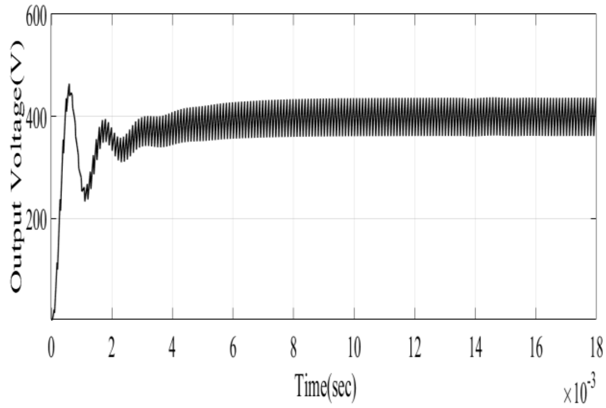

Fig. 15: Output voltage response at V_{dc}=275 and R =250 Ω

4. Conclusion

The proposed system presents the modelling of a step up converter topology for solar or wind energy system installations. Based on the simulation responses in MATLAB, steady state error appears in the open loop system is resolved using the closed loop PID control technique. PID controller has small hardware and less cost. Simulation results realize improved constant output voltage with tracking of reference voltage by Trial and Error method tuning technique of PID control. Moreover, discussed system topology can also be effectively utilized in the fuzzy logic controller scheme.

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