# Hybrid Solar and Wind Power Conversion Using DFIG with Grid Power Leveling

*Mrs. S. Sathana and Ms. Bindukala M.P.*

*Abstract:* **Renewable energy systems are being used more prominently nowadays because they are environment friendly. Also, the lack of availability of fossil fuels leads to the use of solar and wind energy. This paper makes use of a hybrid solar-wind energy system. Doubly fed induction generator (DFIG) based Wind Energy Conversion System (WECS) is used. The rotor side converter and grid side converter along with Battery Energy Storage System (BESS) are used since the BESS reduces the power fluctuation on grid due to unpredictability of wind. The grid power leveling concepts are considered .Maximum Power Point Tracking (MPPT) concepts are used to extract maximum power from wind and sun when available. Perturb and Observe algorithm is used for PV array. The proposed system is simulated using MATLAB-SIMULINK.**

***Keywords*—Battery energy storage system (BESS), doubly fed induction generator (DFIG), maximum power point tracking (MPPT), wind energy conversion system (WECS), grid power leveling.**

## I. INTRODUCTION

With the depletion of fossil fuel reserves, increase in the pollution and global warming, many are looking at sustainable energy solutions to preserve the earth for the future generations. Wind energy is capable of supplying large amounts of power but its presence is highly unpredictable as it can be here one moment and gone in another. Similarly, solar irradiation levels vary due to sun intensity and unpredictable shadows due to clouds, birds, trees, etc. The common drawback of wind and photovoltaic systems is that they are intermittent in nature and thus unreliable. These two intermittent sources are combined together and maximum power point tracking (MPPT) concepts are applied to make system more efficient and reliable.

The doubly fed induction generator (DFIG) is used for wind energy conversion systems because of its advantages like reduced converter ratings for power conversion, efficient power capture due to the variable speed operation, improved efficiency, reduced cost and losses, easy implementation of power factor correction and variable speed operation. The total energy output is 20%–30% higher because of variable speed operation. It ensures improved capacity utilization factor and reduced cost per kWh energy generation [2].

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The block diagram of the proposed system is shown in figure1.

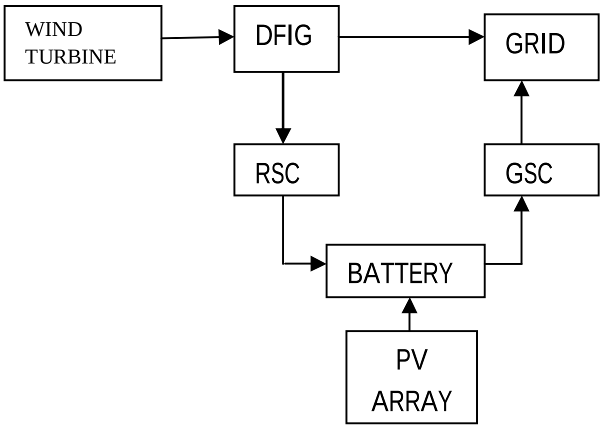


Fig 1: Block diagram of proposed system

In case of WECS, the stator windings of the DFIG are directly connected to the grid and the rotor windings are fed through bidirectional converters to control the rotor and stator output power fed to the grid for variable speed operation. The rotor current injection is controlled using fully controlled electronic converters to ensure effective operation in sub-synchronous and super-synchronous speed modes. The converter handles only around 25% of the machine rated power while the range of the speed variation is 33% around the synchronous speed.

The grid connectivity is a serious issue because of the varying nature and unpredictability of wind speeds. An effective control strategy is used to maintain the output power constant. A battery storage device is used for temporary storage of energy during the period of high wind speeds. The grid is always supplied with constant power irrespective of varying wind speed. This is called as grid power leveling.

## II. MAXIMUM POWER EXTRACTION FROM PROPOSED CIRCUIT

Renewable energy resources like wind and solar energy are intermittent in nature. It is important to incorporate maximum power point tracking (MPPT) schemes to make the system efficient and reliable. The mechanical power generated by the wind is given by;

$$P_m = 0.5 \times C_p(\lambda, \beta) \times \rho \times A \times V^3 \qquad (1)$$

where;

$C_p$ - power coefficient
ρ - air density
$A$ - swept area of rotor blades
λ - tip speed ratio
β - pitch angle
$V$ - wind velocity

The power coefficient (Cp) represents the efficiency of the wind turbine to convert wind energy into mechanical energy. It depends on two variables, the tip speed ratio (TSR) and the pitch angle. The TSR, λ, is the ratio of the turbine angular speed to the wind speed [3]. The pitch angle, β, is the angle in which the turbine blades are aligned with respect to its longitudinal axis.

$$\lambda = \frac{\omega R}{V} \qquad (2)$$

where ;

$\omega$ - rotational speed of generator

$R$ - radius of rotor blades

$V$ - wind velocity

Figure 2 and 3 are illustrations of a power coefficient curve and power curve for a typical fixed pitch ($\beta$ =0) horizontal axis wind turbine. It is clear from figure 2 and 3 that the power curves have a shape similar to that of the power coefficient curve for wind turbines. Since TSR is a ratio between the turbine rotational speed and the wind speed, it follows that each wind speed would have a different corresponding optimal rotational speed that gives the optimal TSR. For each turbine, there is an optimal TSR value that corresponds to a maximum value of the power coefficient (Cp,max) and therefore the maximum power. Therefore, maximum power can be obtained for different wind speeds by controlling the rotational speed of generator.

PV arrays are constructed by connecting numerous solar cells in series and in parallel. A solar cell produces currents based on photovoltaic effect. A PV cell is a diode of a large-area forward bias and the equivalent circuit is shown by Figure 4. The current-voltage characteristic of a solar cell is as shown in figure 5. The equations are given by

$$I = I_{PH} - I_D \qquad (3)$$

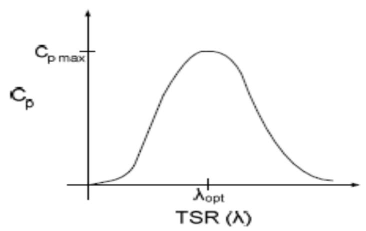


Fig 2: Power Coefficient Curve For a Typical Wind Turbine

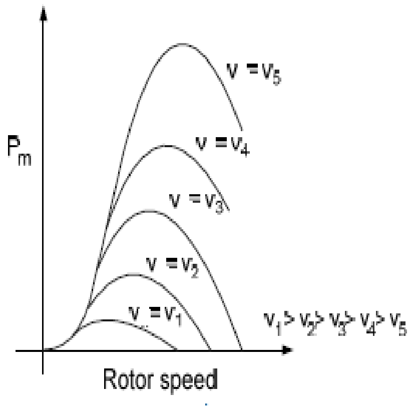


Fig 3: Power Coefficient Curve For a Typical Wind Turbine

$$I = I_{PH} - I_0\left[exp\left(\frac{q(v + R_S I)}{AK_B T}\right) - 1\right] - \frac{V + R_S I}{R_{sh}} \qquad (4)$$

Where

$I_{PH}$ = photocurrent
$I_D$ = diode current
$I_0$ = saturation current
$A$ = ideality factor
$q$ = electronic charge
$K_B$ =Boltzmann's Constant
$R_S$ = series resistance
$R_{sh}$ = shunt resistance
$I$ = cell current
$V$ = cell voltage

It is common to neglect the shunt and series resistances as they are large and small respectively. This simplifies the solar cell model. The resultant ideal V-I characteristic of a photovoltaic cell is given by the equation below and is illustrated in figure5.

$$I = I_{PH} - I_0\left[exp\left(\frac{qv}{kT}\right) - 1\right] \qquad (5)$$

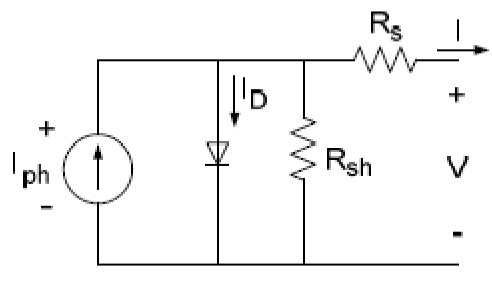


Fig 4. PV cell equivalent circuit

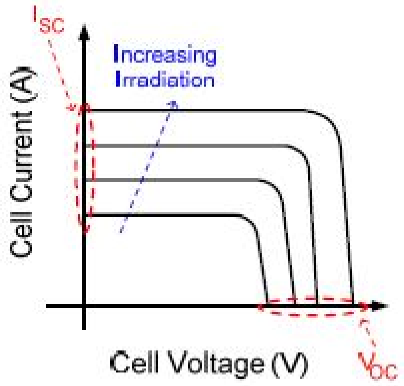


Fig 5. PV cell voltage current characteristics

Figure 6 shows the typical output power characteristics of a PV array under various degrees of irradiation. It is clear from Figure 6 that there is a particular optimal voltage for each irradiation level that corresponds to maximum output power. Thus, the output current (or voltage) of the PV array is adjusted to extract maximum power from the array.

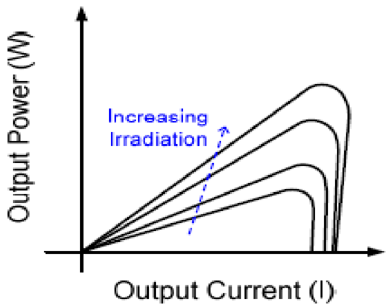


Fig 6.PV cell power characteristics

The Perturb and observe algorithm involves the perturbation of the operating voltage of the DC link between PV array and the power converter. In this method, the next perturbation is decided by the sign of last perturbation and sign of last increment in power. The P and O algorithm is shown in figure 7.

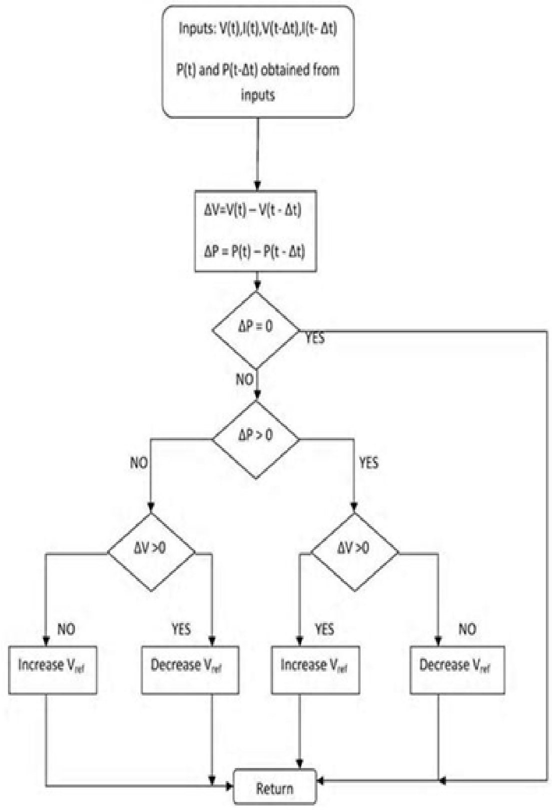


Fig 7.Perturb and observe algorithm

## III. DESIGN AND CONTROL OF PROPOSED SYSTEM

Because of unpredictability of wind, the design of BESS is very important. This section deals with design of wind turbine, BESS and control strategy to obtain grid power levelling [2].

### *A. Design of wind turbine*

The output power of the turbine is given by

$$P_m = 0.5 \times C_p(\lambda, \beta) \times \rho \times A \times V^3 \qquad (6)$$

Where $C_p$ is power coefficient, $\rho$ is air density, $A$ swept area of rotor blades, $V$ is the wind- velocity, λ is the tip speed ratio and β is the pitch angle.

The power coefficient is defined as the power output of the wind turbine to the available power in the wind regime. This coefficient determines the “maximum power” the wind turbine can absorb from the available wind power at a given wind speed. It is a function of the tip-speed ratio and the blade pitch angle. The blade pitch angle can be controlled by using a “pitch-controller” and the tip-speed ratio (TSR) is given as

$$\lambda = \frac{\omega R}{V} \qquad (7)$$

where ω is the rotational speed of the generator and R is radius of the rotor blades

Thus, the TSR can be controlled by controlling the rotational speed of the generator. For a given wind speed, there is only one rotational speed of the generator which gives a maximum value of Cp, at a given β . This is the principle behind "maximum-power point tracking" (MPPT) for a wind turbine.

### *B. Design of BESS*

The design of BESS should be proper necessary for satisfactory operation of WECS. The rating of the BESS is decided by the total energy stored into it and this energy is stored for only those periods in which power generated by the machine is more than the average value that is to be fed to the grid. Knowing the value of the average power to be fed to the grid, the required rating of the battery bank ($E_b$) is calculated as

$$E_b = \sum_{i=1}^{n} P_{mi} \times t_i \quad (8)$$

where $P_{mi}$ is the excess power at any instant than the average value of the power fed to the grid and $t_i$ is the time period for which the excess power is produced. At any instant the value of $P_{mi}$ can be calculated as

$$P_{mi} = \left(P_{inst} - P_{avg}\right) \quad (9)$$

where $P_{inst}$ is the instantaneous power of the wind turbine and $P_{avg}$ is the average active power to be fed to the grid.

### *C. Control of GSC*

The grid power should be maintained at a fixed value and this is given as the reference active power. This is then compared with the actual grid power at any instant. Proportional-integral (PI) controller is used to generate the q-axis component of the reference grid current. The expression for the reference q -axis grid current is as

$$i_{gqref} = \left(k_{pp} + \frac{k_{ip}}{s}\right)\left(P_{gref} - P_{grid}\right) \quad (10)$$

Where $k_{pp}$ and $k_{ip}$ are the proportional and integral constants respectively. The reference d -axis grid current is chosen according to the reactive power sharing between the stator and the GSC. These reference currents are then compared with the actual grid side currents and the error signal is processed with a PI controller to generate the control voltages for the PWM generator on the grid side. The expressions for the control are given as

$$v_{dgsc} = \left(K_{pgsc} + \frac{K_{igsc}}{s}\right)\left(i_{gdref} - i_{gd}\right) \quad (11)$$

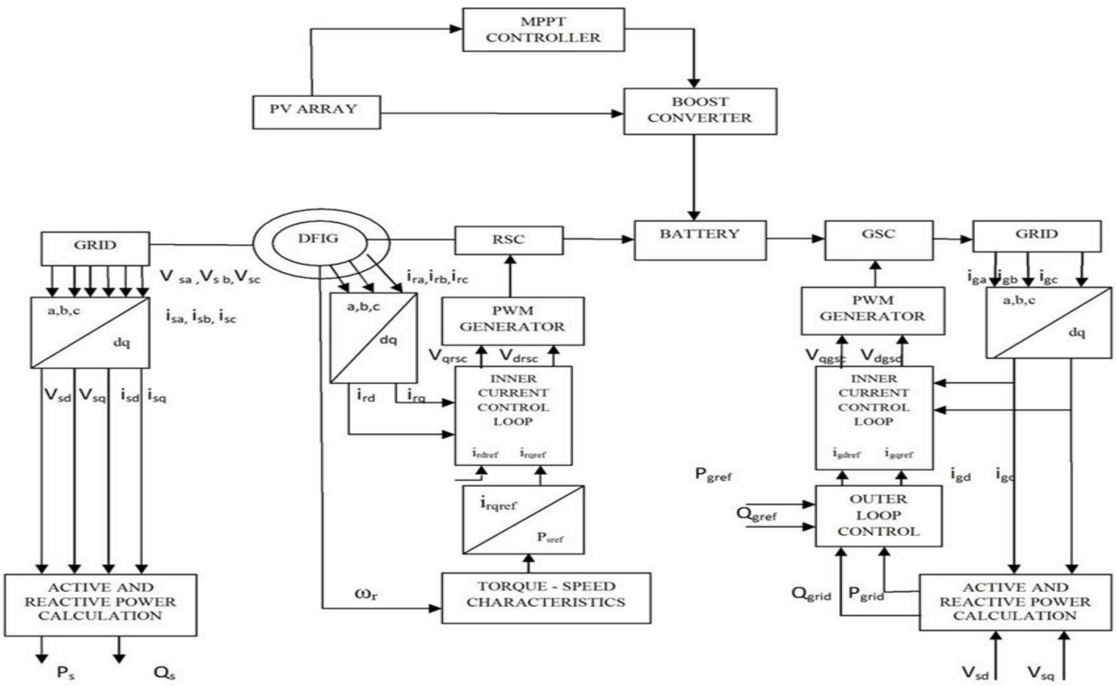


Fig 8. Detailed block diagram of proposed system including control strategy

$$v_{qgsc} = \left(K_{pgsc} + \frac{K_{gisc}}{s}\right)\left(i_{gqref} - i_{gq}\right) \quad (12)$$

Where $i_{gd}$ and $i_{gq}$ are the sensed $d - q$ components of the grid currents and $K_{pgsc}$ and $K_{gisc}$ are the proportional and integral constants respectively.

### *D. Control of GSC*

The control of RSC is to extract the maximum power from the wind. The active power set point is obtained from the instantaneous value of the rotor speed and the rotor current is controlled in the stator flux-oriented reference frame to obtain the desired active power according to the optimum torque speed characteristics.

The reference rotor currents are given by:

$$i_{rqref} = -\frac{L_s}{v_s L_m} P_{sref}$$

$$i_{rdref} = \frac{\phi_s}{L_m} - \frac{L_s}{v_s L_m} Q_{sref}$$

These reference values of rotor currents are compared with the actual values of rotor currents and the obtained error signal is processed with a PI controller to generate the control voltages for the PWM generator on the rotor side.

$$v_{drsc} = \left(k_{prsc} + \frac{k_{irsc}}{s}\right)\left(i_{rdref} - i_{rd}\right)$$

$$v_{qrsc} = \left(k_{prsc} + \frac{k_{irsc}}{s}\right)\left(i_{rqref} - i_{rq}\right)$$

where $i_{rd}$ and $i_{rq}$ are the d-q sensed components of the rotor currents $k_{prsc}$ and $k_{irsc}$ are the proportional and integral constants respectively. These control voltages are fed for PWM generation of the RSC.

### *E. PV array and MPPT*

P and O algorithm is used for MPPT in PV array. PV array can be connected to BESS using boost converter which in turn is controlled by MPPT controller. Boost converter steps up the input voltage to desired level of the battery. The main components of the boost converter; the inductor, the diode and the switch works in coordinated manner to make the output voltage high. The switch is controlled by MPPT controller based on the solar irradiation levels. Thus, maximum power is utilized from the PV array. In case of sufficient irradiation levels, PV array may be used to feed grid directly.

## V. SIMULATION RESULTS

A portion of the proposed system has been simulated using MATLAB-SIMULINK. The matlab model of the WECS is shown in figure 9.The analysis including the PV array is under progress. The results without including the PV array for wind speeds 10m/s,13m/s and 7m/s are given in Figs. 10, 11and 12 respectively. The waveforms for stator voltage ($V_{abc}$), grid current ($I_{abc}$), rotor speed (wr), reactive power (Q), grid power (P) and battery power ($V_{dc}$) are presented for different wind speeds. In all cases, the value of the grid power is maintained to be constant at 5 MW by the modified grid power control strategy. However, this is maintained by either charging or discharging the battery in the corresponding region of operation. The analysis has been performed at variable wind speeds and the grid power is maintained to be constant at the reference value. Hence, the grid power reference is chosen to be 5 MW. The system can be made more reliable and efficient by making it a hybrid system. Photovoltaic array can be used for charging the battery energy storage system (BESS). Also, it can used to meet other local loads. If the solar insolation level is high enough in the place,it can directly feed the grid.

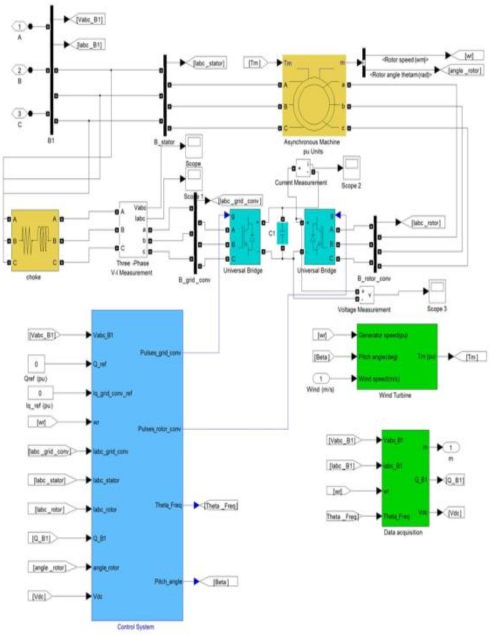

Fig 9: Matlab model of WECS

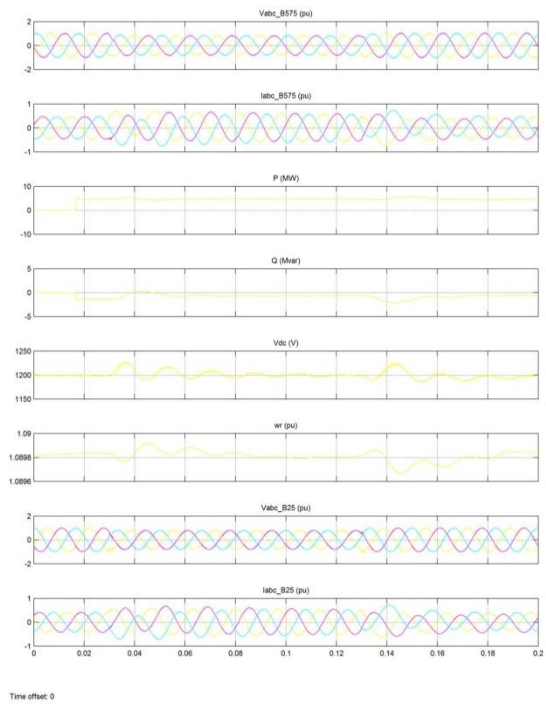

Fig 10: Waveforms for wind speed 10m/s

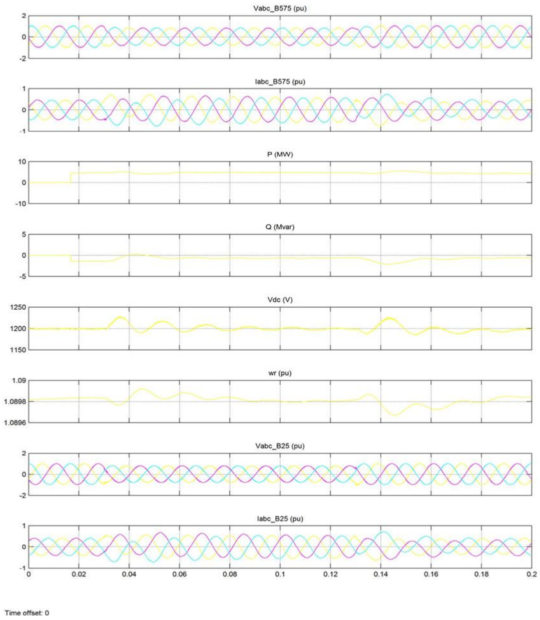


Fig 11: Waveforms for wind speed 13m/s

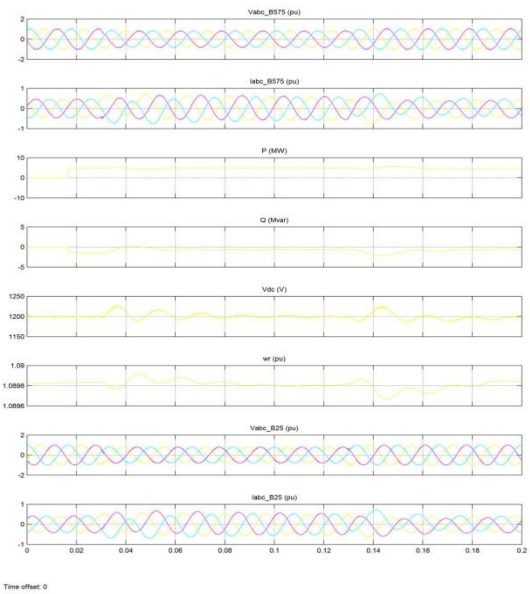


Fig 12: Waveforms for wind speed 7m/s

## VI. CONCLUSION

A hybrid solar-wind energy system has been proposed. A DFIG-based WECS with a BESS has been simulated with a control strategy to maintain the grid power constant. Performance of a DFIG-based WECS with a BESS was studied at different wind speeds. It has been observed that the grid power leveling is obtained with help of BESS. During the periods of over generation, the excess power produced is stored in BESS. When the wind speeds goes low, the stored energy is utilized to maintain grid power constant. The system can be made more efficient and reliable by inclusion of photovoltaic array to obtain a hybrid system. If wind speed goes low for prolonged period, PV array can be used for charging BESS. If sufficient solar energy is available, it can directly feed the grid also.

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