International Journal of Engineering Research and Development
e-ISSN: 2278-067X, p-ISSN: 2278-800X, www.ijerd.com
Volume 8, Issue 8 (September 2013), PP. 18-25

Study of Induction Generator and Inverter for Wind Energy Applications

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Abstract:- For low power wind energy or micro-hydel applications of the order of 1-10KW, the lowest cost can be achieved if the generator is a simple squirrel cage induction motor used as a self excited induction generator (SEIG). The induction generator output can be rectified to produce a DC Bus from which a single phase inverter can feed the power supply grid. A SEIG requires capacitors to be connected to the three terminals to provide reactive power as it is not directly connected to the power supply grid. The aim of the paper is to check the feasibility of wind power generation with a 2 KW squirrel cage induction motor used as a generator. A single phase current hysteresis controlled IGBT inverter is proposed to supply the mains utility power supply with the generated power. The complete system has been simulated.

Keywords:- Induction generator, DC motor, capacitor, rectifier, inverter.

I. INTRODUCTION

The squirrel cage induction motor is one of the most compact rugged and least expensive motor available for industrial use. The induction motor can also act as a generator when it is connected to the grid power supply if its rotor is rotated at super synchronous speed by another prime mover coupled to its shaft [1]. However if the induction motor is to generate power when it is not directly connected to the power supply, it fails to work and no voltage develops. If however capacitors are connected to the terminals in order to supply reactive power, the generator voltage builds up and the induction “generator” is able to supply a load.[2]-[4].

A typical high end wind turbine consists of a tall tower about 80m in height with three blades of diameter 82m across. In the presence of winds the blades can be seen rotating at speeds of 10-20 rpm.about 1 MVA of power is generated. Here generators could be permanent magnet synchronous machines or doubly fed induction generators [3]. Power electronics is used to condition the generated power to supply loads or the mains utility power supply. In the case of remote agricultural areas small wind turbines can be a boon. Here the SEIG can be used so that capital costs are kept lower.

We are proposing that the energy drawn from the wind be fed to the utility power supply through a single phase bridge inverter using current hysteresis control [5]. The inverter may be a IGBT voltage source inverter. The induction generator output is rectified and used to charge a large capacitor which serves as the DC-link voltage for the inverter. An inductance is connected at the output of the bridge inverter connecting to the line and neutral of the power supply.

II. EXPERIMENTAL SETUP TO VERIFY WORKING OF INDUCTION GENERATOR

Fig 1 shows the lab setup to verify the working of an induction generator with a DC motor acting as a wind turbine. The speed of the DC motor is controlled by a ward-Leonard system. The DC motors were of 2 KW, 220V, 1440 rpm rating.

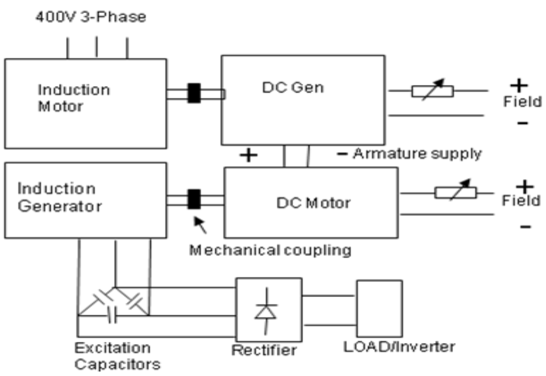

Fig.1: Experimental setup

The induction generator was a 440v, 2KW, 4 pole 1500 rpm squirrel cage motor. Three delta connected AC capacitors of 40 µF each of 440V ratings were connected to the three terminals of the induction generator. The capacitors are of the motor " run " type.

The lab also had a three phase rectifier which had isolation transformer on the AC side to rectify a 400V three phase supply and produce a rectified output of 220V, DC. This allowed us to use a bank of lamp to load the rectifier. While starting about 1-2 minutes are required for the induction generator voltage to develop to 400V (line-line). As expected the output voltage drops when lamp loads are turned on. The rotor speed is increased to keep the induction generator output voltage at 400V (L-L).

Voltages and currents in the motors, generators and rectifier were monitored. The lamp load could be increased to 1035W at which the point the current of DC motor working as the wind turbine reached its limit of 11.6A. The actual capacity of the induction generator with the 40µF excitation capacitors could not be ascertained as the efficiency of the motor limited our ability to load more without exceeding the rated current motor. It was interesting to note that the induction generator developed a voltage of 400V (L-L) while supplying an electrical load of 1KW, when the rotor was rotated at 878rpm although the synchronous speed of the induction machine was 1500rpm. At this mode the efficiency of the generated voltage was found to be 28.5Hz when measured using an oscilloscope.

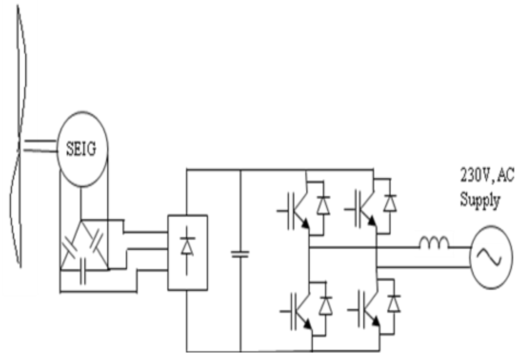

Fig.2: The power circuit of induction generator and inverter.

III. THE PROPOSED INVERTER

Fig.2 shows a cost effective method of feeding the power generated from the wind turbine to the utility mains power supply using a single phase H-bridge circuit. IGBT's are MOSFET's may be used. A current hysteresis control is proposed for the control of the bridge inverter. First the voltage generated by the induction generator is rectified using a three phase diode bridge rectifier. If the induction generator generates 400V (L-L) the output of the rectifier would charge to the peak voltage due to the capacitor. The capacitor voltage would be 556V. The bridge output is connected to the line voltage through an inductor. When switches 1 & 2(fig) are turned on the current flows from the DC-link to the main power supply while being limited by the inductor. When the current exceeds the reference current by the hysteresis amount, switches 1&2 are switched off and switches 3&4 are turned on. This makes the current fall in the inductor as it is now connected to-Vdc. When the current falls below the lower limit 3&4 are turned off and 1&2 are switched on and the process repeats. It can be seen in the inductor which places an important role in limiting the current excursions. The switching frequency depends on the value of the inductor. The switching frequency is also now constant.

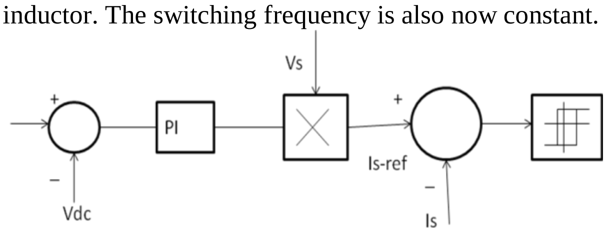

Fig.3: control circuit of the inverter

Fig 3 shows the control circuit of the inverter. There is an outer look that is slow which determines the amplitude of the inductor line current to the fed to the main power supply. The inner loop controls the current using hysteresis or tolerance band control. The capacitor after the rectifier with voltage Vdc is a buffer between the generated voltage and the power fed to the power supply. Vdc is used to adjust the amplitude of the inductor line current using a PI controller. A Hall Effect current sensor such as a LEM is required to sense the inductor current accurately in order for the current control method to work properly. Current Is the current fed in to the power supply through the inductor. The current reference is chosen to be in phase with the power supply voltage

Vs, so that unity power factor is absorbed. This makes the fundamental component of the bridge output voltage lag behind the power supply voltage as in fig4. Also a dead time is required to make sure that top and bottom switches do not turned on simultaneously.

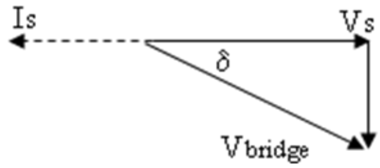

Fig.4: Phasor diagram.

IV. SIMULATION OF THE RECTIFIER

The diode rectifier with capacitor at the output can be simulated if a small inductor is assumed so that circuit equations can be written. The inductor may be made a small value like 0.1μH to get the case when the inductor is absent as in fig.2. The current iL is found as below.

$$iL = \int 1/L(Vin - Vc)dt$$

This integral is carried out only when Vi is greater than Vc and the integrated is reset to zero when the current drops to zero and tries to go negative. The capacitor is found as below.

$$Vc = \int 1/c(iL - iX)dt$$

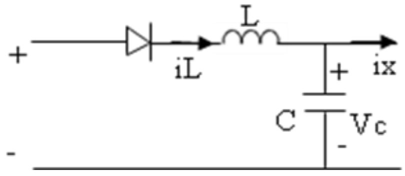

Fig.5: Equivalent circuit of rectifier.

Here Vi is taken as the maximum of the three line to line voltages at the output of the induction generator across the delta connected excitation capacitors.

V. SIMULATION OF THE INVERTER

The switching function U is the out put of the hysteresis current controller is fig3, when U is on (1) the switches 1&2 in the bridge circuit in fig2 are turned on and when off(0), switches 3&4 are turned on. This result in reversing the voltage applied to inductor and power supply, this can be seeing in fig6 which shows the working of the IGBT H-bridge.

$$iL1 = \int 1/L1[(U - \bar{U})Vc - VsSin(\omega t)]dt$$

Where iL1 is the inductor current. Vs is the main power supply voltage to which wind energy is being sent. The output current ix of the rectifier is related to the inductor current as below.

$$iX = (U - \bar{U}).iL1$$

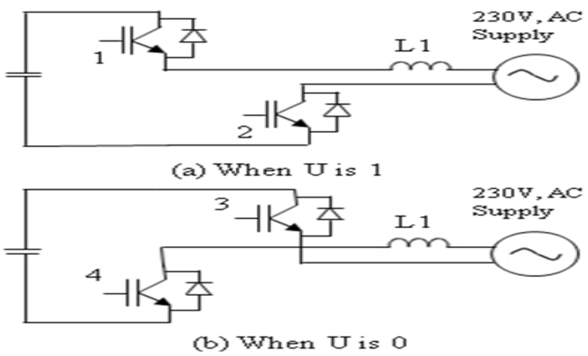

Fig. 6: inverter configurations

VI. CIRCUIT SIMULATIONS

Hysteresis current control

In the non-inverting configuration, when the input is higher than a certain chosen threshold, the output is high; when the input is below a different (lower) chosen threshold, the output is low; when the input is between the two, the output retains its value. The trigger is so named because the output retains its value until the input changes sufficiently to trigger a change. This dual threshold action is called *hysteresis*, and implies that the Schmitt trigger has some memory.

This is an implementation of a "non-inverting" Schmitt trigger. However, for intermediate inputs, the state of the output depends on both the input and the output. For instance, if the Schmitt trigger is currently in the high state, the output will be at the positive power supply rail ($+V_S$). V_+ is then a voltage divider between V_{in} and $+V_S$. The comparator will switch when $V_+=0$ (ground). Current conservation shows that this requires $\frac{Vin}{R1} = -\frac{Vs}{R2}$ and so V_{in} must drop below $-\frac{R1}{R2}Vs$ to get the output to switch. Once the comparator output has switched to $-V_S$, the threshold becomes $+\frac{R1}{R2}Vs$ to switch back to high. So this circuit creates a switching band centered around zero, with trigger levels $\pm\frac{R1}{R2}Vs$. The input voltage must rise above the top of the band, and then below the bottom of the band, for the output to switch on and then back off. If R_1 is zero or R_2 is infinity (i.e., an open circuit), the band collapses to zero width, and it behaves as a standard comparator. The output characteristic is shown in the picture on the right. The value of the threshold *T* is given by $\frac{R1}{R2}Vs$ and the maximum value of the output *M* is the power supply rail.

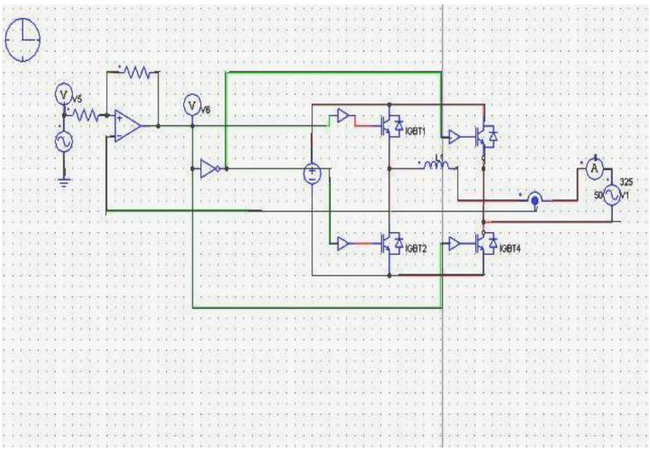

Fig.7: circuit diagram of hysteresis current control

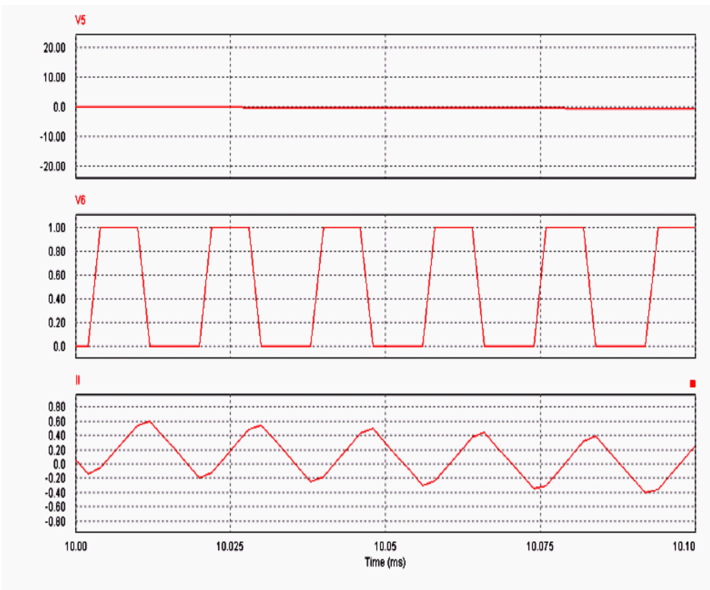

Fig. 8: simulation result

Hysteresis current control with dead time

The circuit diagram shown below consists of Schmitt trigger concept with delay time to control the current. The amount of hysteresis control by the resistance R_1 and R_2. V5 is the input voltage applied to the comparator. V6 is the output of the comparator is switches through dead time circuit. A current hysteresis control proposed for the control of the bridge inverter. The switching frequency depends on the hysteresis level. There has to be a dead time in order that top and bottom switches are not conduct simultaneously. Once switches 1 2 will conduct after some delay switches 1,2 will be in off condition and switches 3,4 will conduct. If a delay is given in the rising edge of the both upper and lower switches of the gate drive circuits the dead time will produced. During this period current freewheeling through the ant parallel diodes in the switches will occur. The circuit diagram and the simulation result shown below.

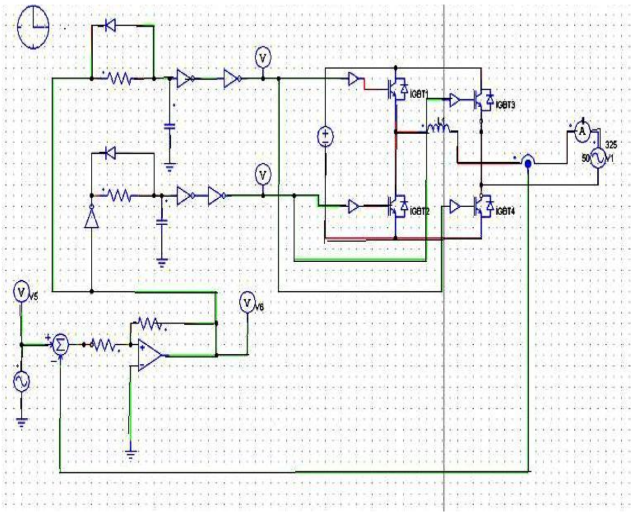

Fig.9: circuit diagram of hysteresis current control with dead time

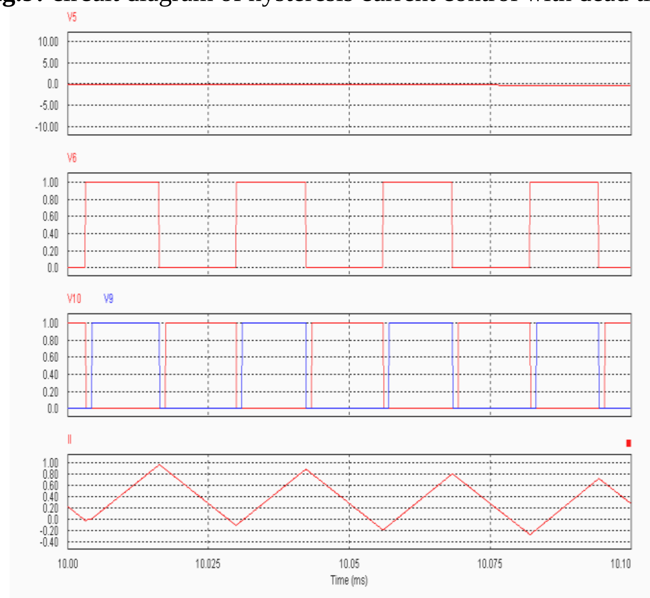

Fig. 10: simulation result

Complete circuit diagram of the project

The complete project circuit diagram shown in above fig 11. we assumed three phase voltage from ward Leonard motor generator system, the induction generator output can be rectified to produce a DC bus from which a single phase inverter can feed the power supply to the grid. A self excited induction generator requires capacitors to be connected to the three terminals to provide reactive power as it is not directly connected to the power supply grid.

The induction motor can also acts as a generator when it is connected to the grid power supply if its rotor is rotated at super synchronous speed by another prime mover coupled to its shaft. The energy drawn from the wind be fed to the utility power supply through a single phase bridge inverter using current hysteresis control. The inverter is IGBT voltage source inverter.

It is essential to insert a switching delay time in hysteresis current control voltage fed inverters to prevent a short circuit in the dc link. The switching frequency depends on the hysteresis level and the value of the inductor at the bridge output. The switching frequency is also not constant. The gate pulses to all the switches should be stopped if the DC-link voltage across the capacitor falls below the peak power supply voltage. The simulation results are shown below.

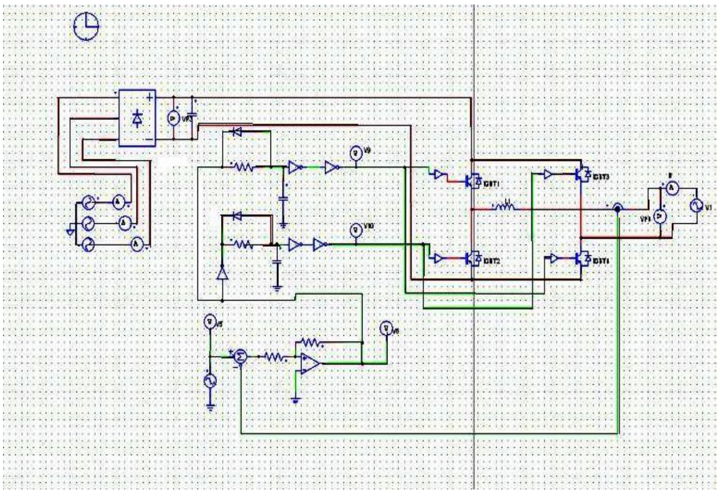

Fig.11:complete circuit diagram

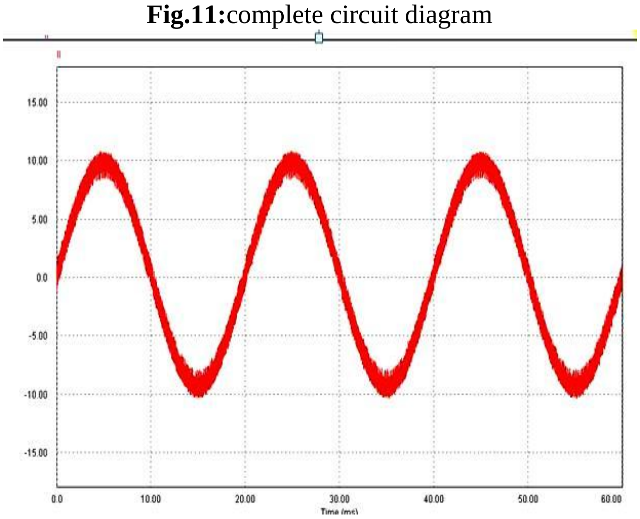

Fig.12: line current

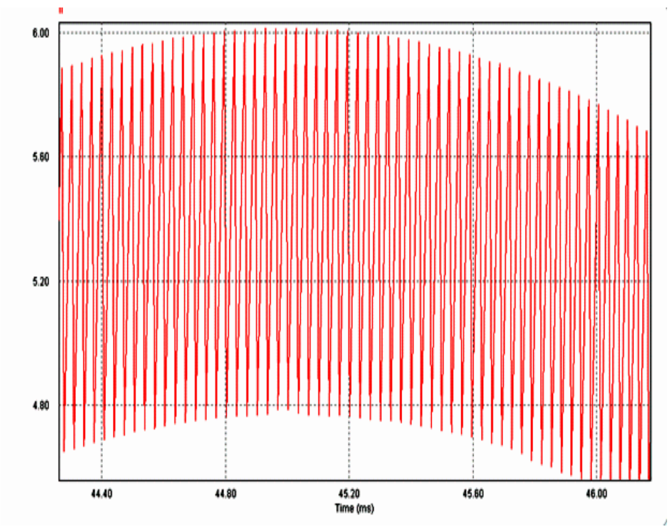

Fig.13:Tolerance band current hysteresis

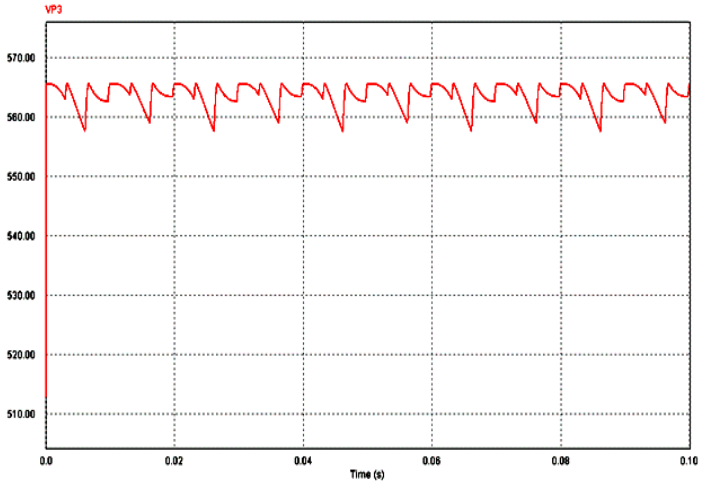

Fig.14:capacitor voltage

Fig 12 shows the line current when a 5A reference current is set in the current hysteresis controller. A tolerance of +/- 1A is set, hence a current band is observed. This tolerance can be set lower also.

Fig 13 shows a magnified view of the current in figure 12. Using the relationship V=Ldi/dt. One can estimate the switching frequency for a 1mH inductor. It is in the order of 150 KHz.

VII. SOME PRACTICAL ASPECTS

For the inverter to work satisfactorily the voltage across the capacitor at the output of the rectifier must be greater than the peak mains power supply voltage. The capacitor voltage tends to increase if the generated power exceeds the power being fed to the mains power supply. When this happens the PI control increases the magnitude of the current in the hysteresis controller. On the other hand if the generated power is lesser than the power fed to the mains power supply, the reference current of the hysteresis controller is reduced by the PI control.

The switching frequency depends on the hysteresis level and the value of the inductor at the bridge output. The switching frequency is also not constant. The switches used could be MOSFETs instead if IGBTs if switching frequency is of the order of 100KHz.MOSFETs could be easily parallel to increase the current capacity. Also the gate pulses to all the switches should be stopped if the DC-link voltage across the capacitor falls below the peak power supply voltage. There has to be dead time in order that top &bottom switches are not on simultaneously. During this period current free-wheeling through the ant parallel diodes in the switches will occur. The hardware setup required is straight forward and can be accomplished with analog circuits. At maximum wind levels the current reference can be high and reducing as the wind level drops.

VIII. CONCLUSIONS

This paper looks at the practicality of using an induction generator for wind energy applications and discusses the use of a simple H-bridge inverter circuits with current hysteresis control to feed power to the mains power supply. The working of a 2KW induction generator has been verified in the lab. Three excitation capacitors of value 40 µF each were delta connected across the three terminals of the squirrel cage induction machine and were found to work up to 1KW(electrical load) and more[4]. This method could be of great help in small scale wind power plants producing up to 10KW or so. Above this power level a doubly fed induction machine is found to be better.

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