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Autotransformer Betters Motor Phase Conversion

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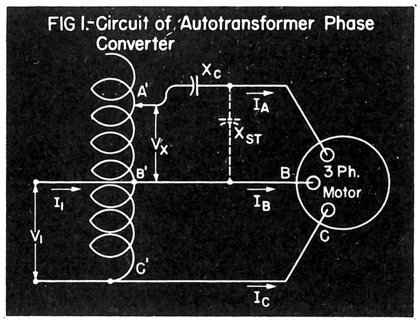

FIG I-Circuit of Autotransformer Phase Converter

Autotransformer Betters Motor Phase Conversion

Circuit of new static unit provides 3-phase currents to 3-phase induction motor from a single-phase line and also has a low starting kva requirement

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A new type of phase converter for stepping up voltage of one line employs an autotransformer in conjunction with the usual series capacitor. Its use permits relaxation of many limitations on the application of the capacitor-only phase converter, over which it has these advantages:

1. It is the only static phase converter available whose circuit provides balanced 3-phase currents to a 3-phase induction motor from a single-phase line.

2. The starting kva it requires is much less than that of a single-phase motor or a 3-phase motor on balanced 3-phase power.

3. Power factor is improved throughout the operating range of the motor.

4. Starting torque compares favorably with that of a single-phase motor.

5. Starting kva per ft-lb is less than that of the single-phase or 3-phase motor.

6. Cost of autotransformer phase converter and 3-phase motor is competitive with that of a single-phase motor.

7. Simplicity of the 3-phase motor reduces maintenance.

8. Where 3-phase power may eventually become available, it permits immediate use of 3-phase motors.

9. Converter units of a given horse-power rating may be used with motors smaller than that rating.

A 3-phase motor operates ideally when balanced 3-phase voltages applied to the motor terminals result in balanced line currents. Theoretically this balance prevails for phase converter-operated induction motors when the following equation is satisfied:

$$Z_m\underline{/\theta_m}(N\underline{/0^\circ} + 1\underline{/-60^\circ}) = \frac{X_c}{\sqrt{3}}\underline{/0^\circ} \ldots \quad (1)$$

where:

Z_m = impedance per phase of the induction motor.
θ_m = power factor angle of the induction motor.
$N = \left|\frac{V_x}{V_{BC}}\right|$ as given by tap setting on the autotransformer.
X_c = reactance of capacitors in series with line A (Fig 1).

As both autotransformer tap setting N and capacitive reactance X_c may be varied, the above equation can be satisfied for any polyphase induction motor, thus assuring balanced operation at a particular load. As load requirements change, the motor no longer has exactly balanced currents. Accordingly, the values of N and X_c must be adjusted initially to give balanced operation for the load condition normally encountered.

The theory of other types of phase converters may be treated as a special case of the autotransformer phase converter. Adjusting the tap setting A′ to point B′ makes V_x equal to zero. The autotransformer then has no effect on the operation of the phase converter, and the circuit is identical with that in the capacitor-only phase converter. When N equals zero, equation (1) becomes

$$Z_m\underline{/\theta_m - 60^\circ} = \frac{X_c}{\sqrt{3}}\underline{/0^\circ} \ldots \quad (2)$$

This equation can only be satisfied when

$$\theta_m = 60^\circ$$
$$X_c = \sqrt{3}Z_m \ldots \quad (3)$$

From equation (3) it is seen that only the special case of power factor equal to 0.5 can be balanced. Usually this occurs only when the machine is very lightly loaded. Consequently the autotransformer is essential in phase converters to obtain the desired balanced operation for a motor operating under load.

Table I gives operating characteristics of the autotransformer phase converter derived from tests with a 3-phase, 220-v, 60-cps induction motor rated at 3 hp at 1,165 rpm. Load runs were made with the motor connected directly to a 3-phase line and again to a single-phase line through the phase converter. Separate runs were made for the phase converter adjusted to give balanced conditions.

Results of two runs with the phase converter set to give a balance at 70 and 110% of rated output are shown in Fig 2, where variation in line current is plotted as a func-

Table I—Operating Comparison, 3 H.P. Induction Motors

	3 Ø Motor on 3 Ø	3 Ø Motor, Autotran. Ph. Converter		Single ⊙⊙ Phase Motor
		70% Balance	110% Balance	
Line Volts	220	220	220	230
Breakdown Torque (% Rated Torque) ⊙	250%	138%	145%	200%
Starting Current (Amps)	48	53	58	70
Starting Torque (% Rated Torque) ⊙	210%	155%	195%	175%
Starting kva	18.3	11.7	12.8	16.1
Starting kva/ft-lb.	.645	.57	.49	.68

⊙ Rated Torque = 13.5 ft.-lbs.
⊙⊙ Capacitor Start – Capacitor Run

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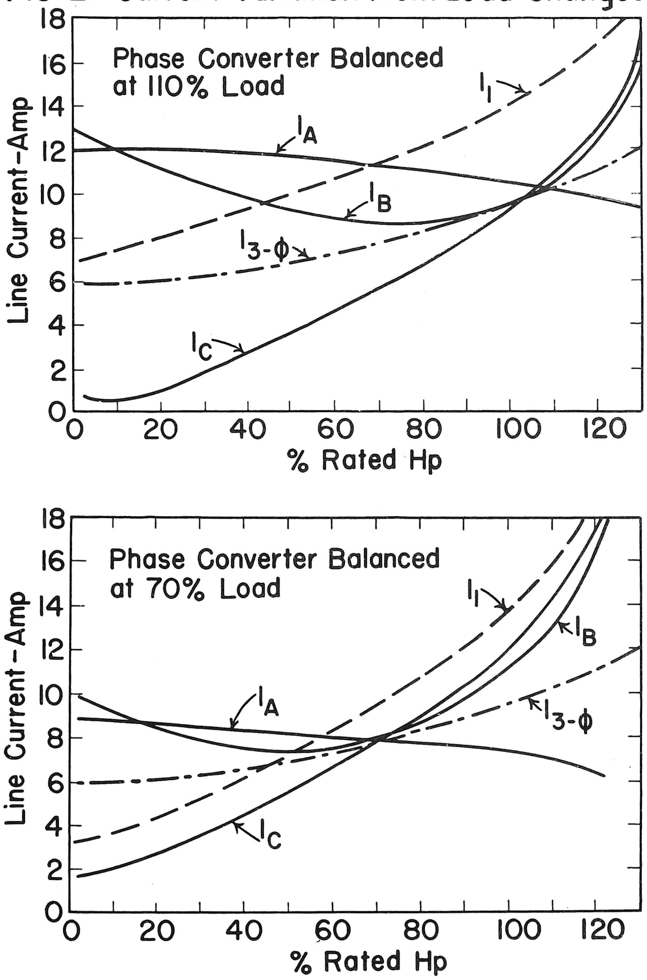
FIG 2.-Current Variation from Load Changes



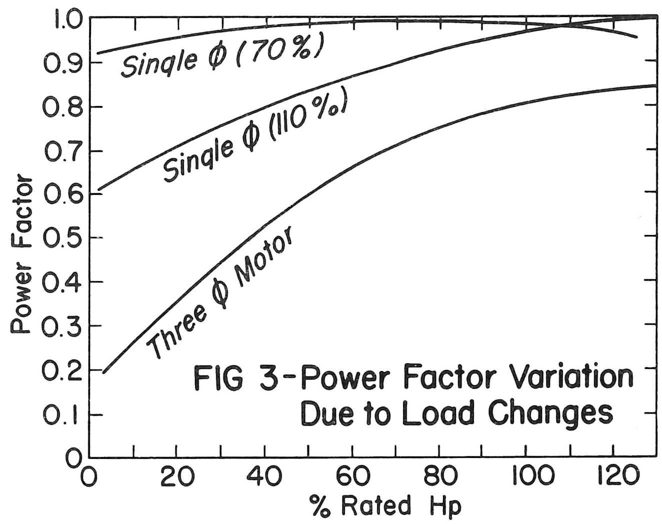


FIG 3-Power Factor Variation Due to Load Changes

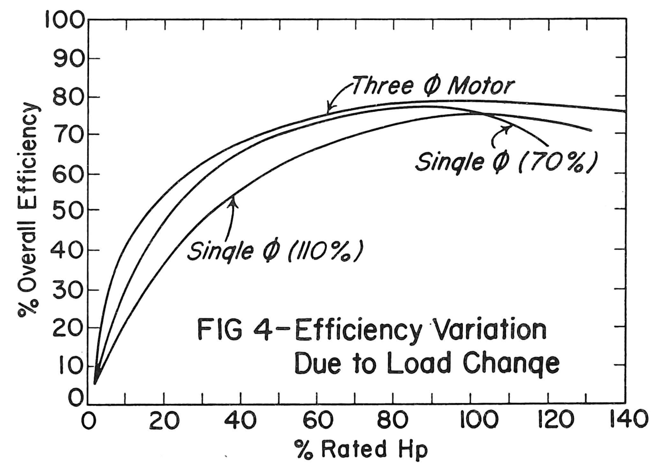


FIG 4-Efficiency Variation Due to Load Change

tion of horsepower output. The curves show that line currents can be balanced at particular load values, although current unbalance varies considerably as load increases or decreases from the point of balance.

Voltage variation because of line drop is a serious problem on rural single-phase lines. As voltage drop is proportional to line current, it is desirable to keep line current for a given power at a minimum. In other words the power factor should be as close to unity as possible. The excellent single-phase power factor characteristics of the autotransformer phase converter are compared in Fig 3 with the power factor of the 3-phase motor.

In matching a motor to a given load, torque variation as a function of speed is the most important factor. A motor operated through the phase converter has a speed-torque characteristic very similar to that of a motor operated directly on 3-phase up to loads of about 120% of rated horsepower. For loads in excess of this value speed drops very rapidly, and the breakdown torque is much lower than for 3-phase connection. For certain types of load occasionally requiring excessive torques, it may be necessary to use the next larger size motor.

The overall efficiency on single-phase using the phase converter is almost the same as the motor efficiency on balanced 3-phase. The only losses in the phase converter are core and copper losses of the autotransformer. Additional losses, however, occur in the motor for unbalanced operation because of negative sequence losses. This results in overall efficiencies approximately equal to the efficiency on 3-phase at points of balance. As unbalance increases, the overall efficiency decreases because of the additional motor losses, as shown in Fig 4.

For starting an additional capacitor X_{ST} is required in the circuit to provide the required starting torque. This capacitor tends to balance currents at starting and is disconnected by means of a relay circuit sensitive to voltage V_{AB} after the motor comes up to speed. Characteristics at starting (locked rotor) are given in Table I. Characteristics of 3-hp, single-phase, general-purpose induction motors, as taken from recommended values in NEMA Standards, are also given for comparison.

The autotransformer phase converter thus has the lowest, ie, most desirable, value of kva per ft-lb at starting, and the autotransformer is just as essential to the circuit at starting as it is during running conditions. Recent tests on capacitor-only phase converters indicated a starting kva per lb-ft of 0.86, compared with 0.57 for the autotransformer phase converter balanced at 70% rated load.

The autotransformer phase converter-3-phase induction motor combination can be used as a source of power where only single-phase is available without the usual excessive voltage drop during starting. For loads requiring almost constant power the unit can be adjusted to give balanced operation at a high power factor for the particular load.

The autotransformer phase converter has two disadvantages. Although comparable to that of a single-phase motor, its breakdown torque is less than that of the 3-phase induction motor on balanced 3-phase power. Also, its starting torque is about 85% of that of the 3-phase motor and about that of a single-phase induction motor.

PUBLICATIONS OF THE ENGINEERING REPRINT SERIES

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