necessarily mean that corrective equipment must always be installed, but in most cases it is desirable to determine what advantages may be gained by improving the power factor. With purchased power, if the rates include a clause embodying a penalty for low power factor, or a bonus for high power factor, the saving in power costs may often make a very good return on the investment required for the corrective equipment.

Synchronous motors are used to drive fans, blowers, pumps, compressors, and other applications. Compressor applications having a high peak torque require the use of flywheels to smooth out power peaks, and should always be referred to the electrical manufacturer for recommendations.

Synchronous motors are provided with built-in damper windings on the rotor and operate during the starting period similarly to squirrel-cage motors. After the motor is nearly up to speed, field excitation is applied and the motor draws into step at synchronous speed. After excitation is applied, the motor runs at exactly constant speed and will remain at this speed until a load approaching the pull-out load is reached, whereupon the motor pulls out of synchronism and stops.

In applying synchronous motors, consideration must be given to the torque the motor can develop on pull-in, that is, at the instant when field excitation is applied. Table 5 shows typical application requirements of synchronous motor drives, listing starting, pull-in, and pull-out torques.

Multi-Speed motors provide flexibility in many types of drives. Synchronous motors can be furnished only with a 2 to 1 ratio in speed, single-winding. Squirrel-cage induction motors may be 2-, 3-, or 4-speed. Two-speed induction motors are usually of single-winding type, having a 2 to 1 speed ratio such as 600 rpm and 1200 rpm, or may be double-winding. Three-speed induction motors are always two-winding, and four-speed motors are usually two-winding with a 2 to 1 speed ratio in each winding. Motors can be provided in constant torque, varying torque, or constant horsepower ratings. The constant horsepower type of motor is considerably larger than the constant torque motor, due to the fact that the same horsepower must be developed at either reduced speed or high speed.

In selecting two-speed motors for fan, pump, blower, or compressor applications, it is usually found that two-winding motors are more expensive than the single-winding type. The control cost for two-speed, two-winding motors, however, is more economical, and therefore the combined price of both motor and control for the two-winding motor is only slightly higher. Because of the improved performance of the two-winding motors, and because of the factor of safety provided by two independent windings, the increased cost is frequently worth the difference.

Single-phase Motors

Single-phase induction motors have auxiliary windings or devices for starting, and are classified by the method used.

Capacitor-start motors develop high starting torque in fractional horsepower ratings, and moderate starting torque in larger ratings. They are used for constant speed drive such as fans, blowers, and centrifugal pumps. During the starting period, a winding with a capacitor in series is connected to the motor circuit and when the motor comes up to speed, a centrifugal switch cuts the capacitor and second winding out of the circuit.

Two-value-capacitor motors develop high starting torque employing a starting capacitor and a running capacitor. The starting capacitor gives high starting ability, but is suited for short time operation only, and is cut out for the running condition by a centrifugal switch. The running capacitor gives high efficiency at full speed. These motors are used on compressors, reciprocating pumps, and similar equipment which may start under heavy load.

Permanent-split-capacitor motors have low starting torque and are ideally suited for small fan drives. Operation is similar to the capacitor-start motor, except that the capacitor is not cut out when running. These motors, when equipped with a high-slip rotor, may be used for adjustable-speed operation by employing line voltage control, or a tapped winding.

Repulsion-start Induction-run motors develop high starting torque. The motors have a wound rotor connected to a commutator for starting. A centrifugal switch shorts the commutator bars when the motor comes up to speed to obtain a winding approximately like the squirrel-cage in its function. These motors are suitable for applications, such as industrial compressors, requiring high breakaway torque, and where commutator and brush noise are not factors.

Split-phase motors have a high-resistance auxiliary winding which is in the circuit during starting, but is disconnected through the action of a centrifugal switch as the motor comes up to speed. Under running conditions it operates as a single-phase induction motor with one winding in the circuit. These units are available in fractional horsepower ratings and are ideally suited for fan duty.

Speed-torque characteristics of single-phase motors are shown in Fig. 4.

Full-voltage starting of single-phase motors is general practice, but since most of these motors are connected to secondary distribution systems located in light-load density areas, power companies check carefully the starting currents in order to prevent objectionable voltage dips. This is particularly important for motors started frequently, such as those controlled by pressure or temperature-sensitive devices and applied to refrigerators, stokers, oil burners, and water pumps.

The report of a joint committee of AIEC-EEI-NEMA recommended three application rules taking into account the greater annoyances resulting from frequent motor starting during lighting hours against infrequent starting at any time. Table 6 shows typical applications of these rules which are becoming widely accepted for full-voltage starting. Rules 1 and 2 apply to general use.

Rule 1 limits the locked-rotor current to 20 amp at 115 volts, and 25 amp at 230 volts when automatically controlled (usually frequently started) motors are used. Rule 2 permits twice these values when manually controlled (usually infrequent starting) motors are used. Rule 3 applies to special conditions where larger currents may be allowed above Rules 1 and 2 upon approval of the electric company.

Hermetically-enclosed single-phase a-c motors are widely used in appliances such as domestic and commercial refrigerators, room air conditioners, beverage coolers, freezer chests, and water coolers. Larger sizes are employed in air conditioners, condensing units and heat pumps. The motors are sealed inside the compressor, and the gas and oil circulate freely within and around the motor. Centrifugal starting switches are not used on such motors because any arcing in the gas and oil atmosphere would be detrimental, and also because the units are permanently sealed and are difficult to service or repair in the field. In place of a centrifugal switch, an external relay is used to start hermetically-enclosed motors.

Hermetically-enclosed motors for refrigeration compressors will, in the future, have the horsepower rating eliminated. The full-load current is to be the operating current in amperes, when the compressor is delivering rated output. The motors for hermetically-enclosed service are usually of the

Table 5 .... Typical Application Requirements of Synchronous Motor Drives Showing Starting, Pull-In, and Pull-Out Torques

	Application	Method of Connecting Motor to Load	Starting Conditions	Torques			Remarks
				Starting	Pull-In	Pull-Out	
Fans	Exhaust and ventilating	Coupled or belted	Usually loaded	50	60–125	150	WR^2 of fan must be considered
Blowers	Cycloidal positive	Coupled or engine type	Unloaded	40–60	40–60	150	Two-speed motors sometimes used
	Blowing engines reciprocating	Engine-type	Unloaded	40	40–60	150	
	Turbo high speed	Direct connected or step up gear	Unloaded (intake closed)	30	50	150	WR^2 of blower must be considered
Compressors	Air	Engine-type	Unloaded	40	30	150	Flywheel effect important
	Ammonia and ammonia booster	High speed—belted Low speed—engine-type occasionally coupled	Unloaded (by bypass)	40	30	150	Flywheel effect important
	Freon	High speed—belted Low speed—engine	Unloaded (by bypass)	45	50	150	Flywheel effect important
	Gas reciprocating	High speed—belted Low speed—engine	Unloaded (by bypass)	40	30	150	Flywheel effect important

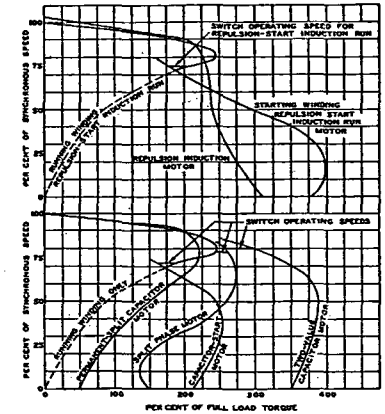

Fig. 4 .... Speed Torque Characteristics of Single-phase Motors

Table 6 .... Recommended Single-Phase Motor Ratings for Full-voltage Starting

HP Rating	Locked-rotor Current* at 25 C Amperes		General Use (Rules 1 & 2)		Special Conditions (with Utility Permission) (Rule 3)	
	115 V	230 V	115 V	230 V	115 V	230 V
1/20	20	10	A-M	A-M	A-M	A-M
1/6	20	10	A-M	A-M	A-M	A-M
1/6	20	10	A-M	A-M	A-M	A-M
1/4	23	11.5	A-M	A-M	A-M	A-M
1/3	31	15.5	M	A-M	A-M	A-M
1/2	45	22.5	M	A-M	A-M	A-M
3/4	61	30.5		M	A-M	A-M
1	70	35		M	A-M	A-M
1 1/2		40		M		A-M
2		50		M		A-M
3		70				A-M
5		100				A-M

A refers to automatically controlled devices.
M refers to manually controlled devices.
* These values of Locked-rotor current are the same as the NEMA standard for single phase Design M motors.