



ST62 MICROCONTROLLERS DRIVE HOME APPLIANCE MOTOR TECHNOLOGY

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INTRODUCTION

Most domestic appliances are driven by an electric motor; for the most part, these motors are controlled in a simple and rudimentary fashion, and electronics is only now beginning to be applied. This article describes the three main motor families – Universal, Induction and Electronically Commutated – as well as the relevant electronic control techniques, now possible thanks to the intrinsic characteristics of STMicroelectronics ST62 Family of microcontrollers.

ST62 MCUs, with their wide range of on-chip peripherals, their wide supply voltage range, their built-in ruggedness and their legendary noise immunity allow truly low total system cost, thus favouring the technological advancement of electrical motor design.

Basic electrical topologies are described, together with their associated power and signal electronics. The relative strengths and weaknesses are explored, using practical examples, in order to illustrate the advantages of electronic control using ST62 MCUs.

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1 ELECTRIC MOTORS IN DOMESTIC APPLIANCES

In home appliances and light household equipment, electronics is commonly found in the man-machine interface (dashboards, control panels, remote controls, etc...), as well as in the management of complex operating sequences, such as in washing machines; however, it is only just beginning to be used to control the electric motors which power them.

Energy saving, silence, flexibility and simplicity are requirements of growing importance: in applications such as drills, vacuum-cleaners and refrigerators, variable speed control is the principal means of obtaining such performance features.

Up to 46 motors are to be found in the various items of domestic equipment in a typical American home^(*). This illustrates the important role that electronics is bound to play in the control of home appliance motors.

Electronics will initially become more common in the control of conventional electric motors, and will subsequently lead to the popularisation of brushless electronic motors, which offer the advantages of being more rugged and of requiring lower cost mechanical parts. These motors naturally require more complex electronic control systems, which will become increasingly viable as the cost of electronic systems falls, thanks to the use of STMicroelectronics ST62 Family of MCUs and low-cost integrated power ICs.

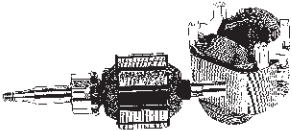
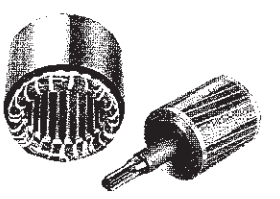
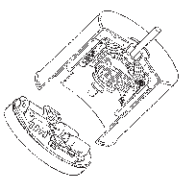
^(*) Emerson in Appliance Manufacturer August '94

2 THE RIGHT MOTOR FOR THE JOB

2.1 CONVENTIONAL ELECTRIC MOTORS

Three main families of electric motors are commonly used in home appliances. Their power can range from 50W to 1.5 kW. The first two families, **Brush Motors** (i.e. Universal Motors) and **Brushless Motors** (i.e. Induction Motors) are the most popular and these cheap and well known motor designs may be connected directly to the AC mains.

Figure 1. Features and typical applications of the three main types of electric appliance motors

| WITH BRUSHES  UNIVERSAL | BRUSHLESS  INDUCTION | BRUSHLESS ELECTRONIC COMMUTATION  AUTOCOMMUTATED Perm. Magnet or Var. Reluctance |
|--|---|---|
| FEATURES <ul style="list-style-type: none"> – AC or DC supplied – High torque at starting APPLICATIONS FIELDS <ul style="list-style-type: none"> – Washing machine (EU) – Hand tools – Food processor – Vacuum cleaner | FEATURES <ul style="list-style-type: none"> – AC supplied – Robust APPLICATIONS FIELDS <ul style="list-style-type: none"> – Washing machine (WW) – Heating-Ventilation-Air conditioning – Immersed pump / Compressor / Fan – Dish washer / Tumble drier – Freezer / Refrigerator | FEATURES <ul style="list-style-type: none"> – Electronic replaces brushes – High torque at starting APPLICATIONS FIELDS <ul style="list-style-type: none"> – Washing machine – H.V.A.C. – Pump / Fan – Food processor – Vacuum cleaner – Freezer / Refrigerator |

- **Universal** (Brush) Motors are used in applications where high torque and/or variable speed are required (e.g. drills, food-processors, hand-tools, vacuum cleaners, etc.). They can be powered either by an AC or DC supply, and are currently the most popular motors in appliances. Due to their poor efficiency and relatively limited life, universal motors are tending to

be replaced by newer types when the cost of the necessary electronic control systems drops to sufficiently low levels.

- **Induction** (Brushless) Motors are mainly used in applications requiring silent operation, long life and high safety levels (i.e. pumps, compressors, refrigerators, fans, etc.). These motors are AC supplied and rotational speed does not vary easily, since it is synchronised with the electrical mains frequency.

In the third family, electronic acts as an electronic commutator and takes the place of brushes.

- **These Electronically Commutated Brushless Motors** include Permanent Magnet Synchronous Motors and Switched Reluctance Motors. Both types are controlled by electronically switching the current in the windings. Electronically Commutated Brushless Motors combine the high torque and variable speed performance of the universal motor with the absence of brushes and the intrinsic ruggedness of the induction motor.

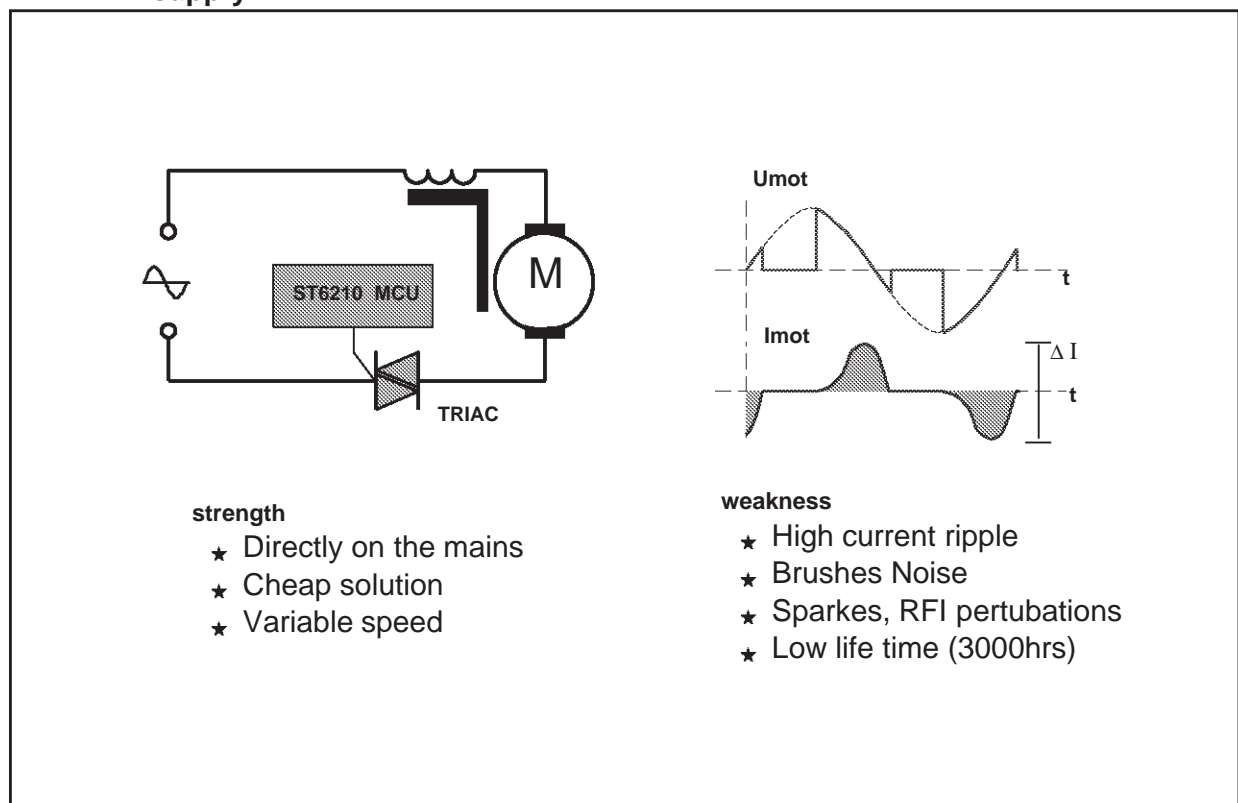
3 UNIVERSAL MOTOR CONTROL

3.1 PHASE ANGLE CONTROL MODE

Universal motor speed may be simply and economically varied by phase angle control using a TRIAC: this is therefore a very popular solution [1]. The motor current is directly drawn from the mains and, because of its large peak to peak value, power losses in the iron are high.

When the TRIAC conduction angle is less than full wave, the current drawn from the mains contains low frequency harmonic components with high amplitudes which can easily exceed the authorised IEC levels.

Figure 2. Universal brush motor driven by phase-angle triggered TRIAC switched AC supply.

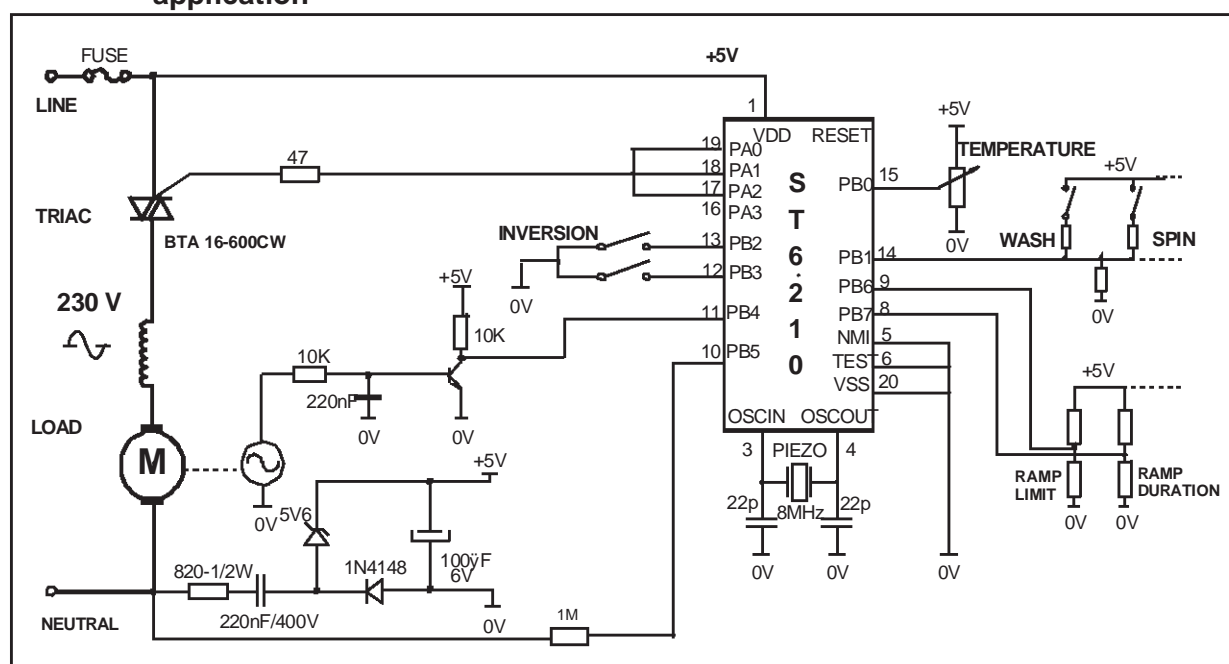


In the example of a washing machine motor controller (Figure 3.), the gate of the TRIAC is directly controlled by a low-cost ST6210 microcontroller. Each high current I/O pin on ST62 Family devices can drive 20 mA, thus one or more pins may be paralleled, depending on the TRIAC's gate drive requirements.

The ST62 Family microcontroller, thanks to its wide voltage supply range and built-in noise immunity, can be directly supplied from the 220V mains using only a few low-cost external components, as illustrated in Figure 3. The ST6210 manages the various washing cycles, the man-machine interfaces and motor speed control. Motor speed regulation can make use of a tacho-generator, or can be sensorless [4].

The ST62 controlled solution is extremely economical, while providing maximum flexibility: changes are simply, rapidly and economically implemented by modifying the ST62 control program.

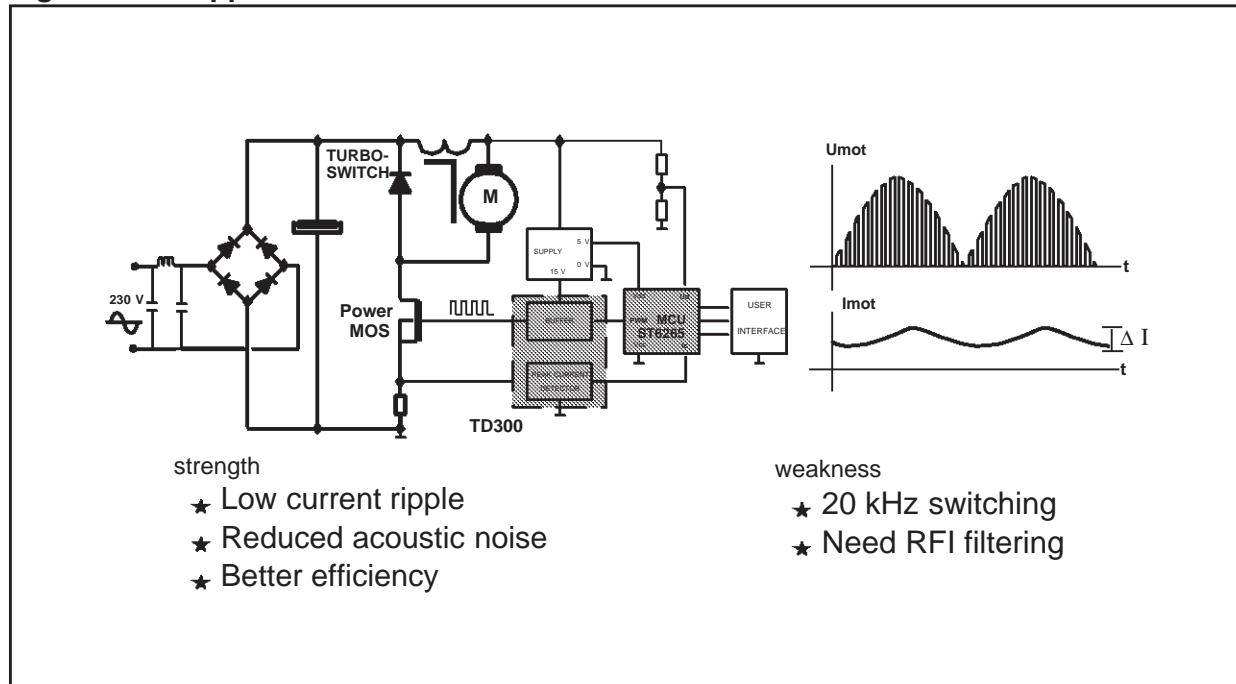
Figure 3. Speed regulation using ST6210 MCU driven TRIAC in a washing machine application



3.2 CHOPPER CONTROL MODE

The universal motor can be supplied by a rectified AC voltage, switched at a high frequency by a power MOS transistor [3] [6]. Speed control is achieved by adjusting the chopper duty cycle [9]. Because of the rectified voltage, the current ripple is low, and iron losses are therefore low as well. (Figure 4.)

Figure 4. Chopper controlled Universal motor. mode



The mains current waveform is sinusoidal and thus does not generate low frequency harmonics.

Chopper control mode is an efficient means of complying with the IEC 1000-2-3 harmonics standard. The pulsed current at the chopper frequency must be filtered to remove components at the switching frequency and above, but the filtering inductance need only be small, and therefore low-cost, since the chopper frequency can be high (5 - 20kHz).

The chopper circuit comprises a power MOS transistor and a fast Turboswitch™ freewheeling diode. The pulse width modulated (PWM) drive signal is generated by the ST62 microcontroller, via the STMicroelectronics TD300 MOS driver IC, which level shifts the 5V microcontroller output to the 15V level needed to drive the gate of the power MOS device. The MOS driver IC also affords protection against short-circuits and over current. The ST62 microcontroller monitors the mains voltage and manages the user interfaces (signals and control).

3.3 HARMONICS AND POWER DRAWN FROM THE MAINS

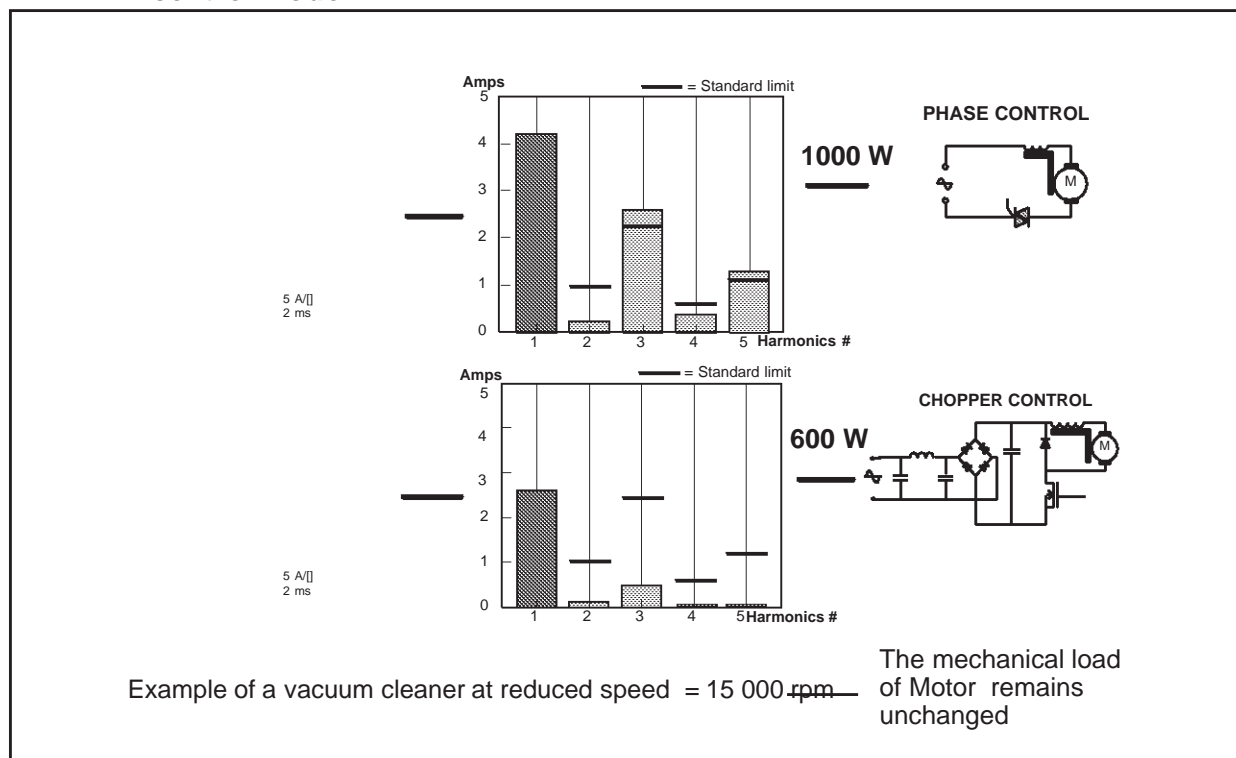
The low frequency harmonics content generated on the mains strongly depends on the kind of motor control used (phase angle or chopper).

For example, a vacuum cleaner operating in phase angle mode at reduced speed (i.e. conduction phase angle at around 90°), produces a very high level of even harmonics (Figure 5.). The harmonics do not represent real or active power, but nevertheless they lead to substantial copper and iron losses. Consequently, the power supplied to the vacuum cleaner for the same mechanical output power is twice as high using phase angle control as it is when the chopping control method is used.

Briefly, the chopper method minimises harmonics on the mains and increases motor efficiency by a factor of two with respect to the phase angle control mode, as illustrated in Figure 5.

Motor size can thus be reduced and brush lifetime is much greater. In addition, in most applications no low frequency filtering or power factor correction is necessary to comply with the IEC1000-2-3 standard. However, the high frequency harmonics generated by the chopper circuit (over 10kHz) must be blocked from the mains by means of a high frequency filter.

Figure 5. Current waveform and harmonics in phase angle control mode and chopper control mode



4 INDUCTION MOTOR CONTROL

4.1 INDUCTION MOTOR SUPPLIED BY MONOPHASE AC

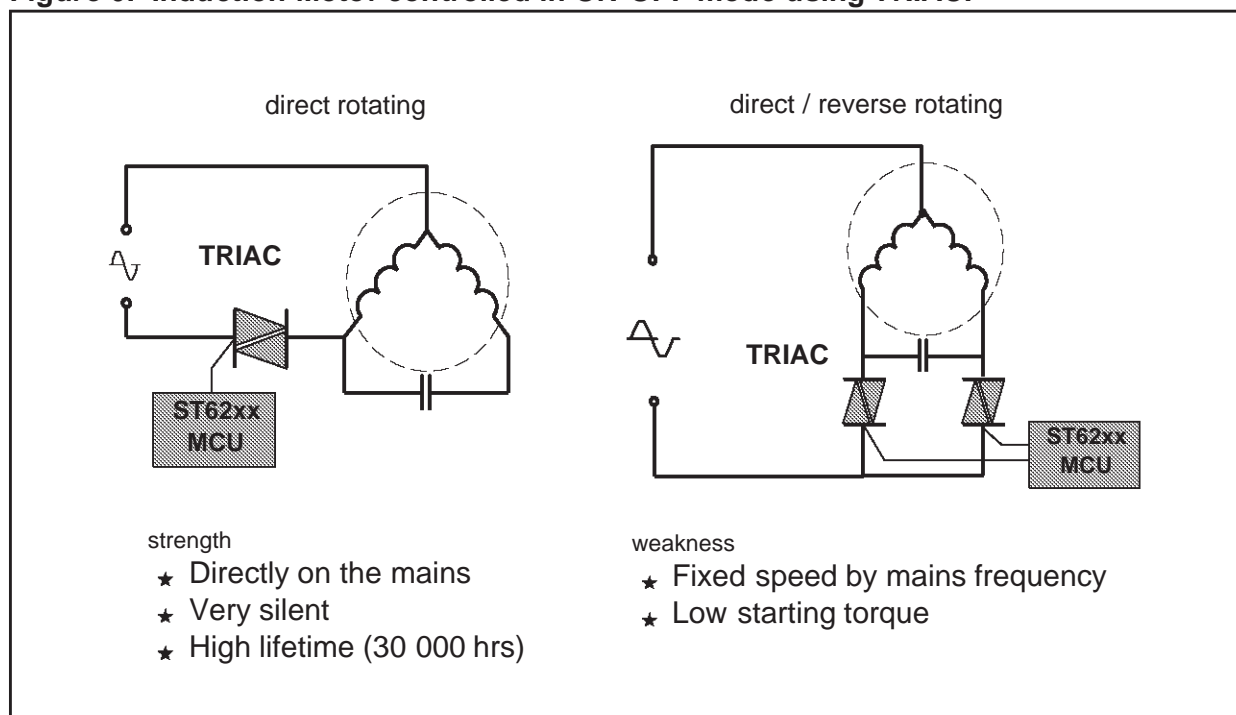
An induction motor (also known as an asynchronous motor) is directly supplied from the monophase mains and can be controlled simply in "ON/OFF" mode using a TRIAC driven directly by a low-cost ST62 Family microcontroller (Figure 6.).

The reverse direction of rotation is obtained by using a second TRIAC controlled by the same microcontroller.

Despite their low cost, these solutions give a great flexibility for design and operation, thanks to the use of a microcontroller, allowing such functions as monitoring of motor torque and mains voltage. Motor losses can be optimized by controlling undervoltage or Figure 3. Speed regulation using ST6210 MCU driven TRIAC in a washing machine application overvoltage according to working conditions and load (rotation speed, acceleration or deceleration, torque demand).

Using this basic control, the motor speed cannot be easily adjusted, as it is fixed by the 50 or 60Hz mains frequency.

Figure 6. Induction Motor controlled in ON-OFF mode using TRIAC.



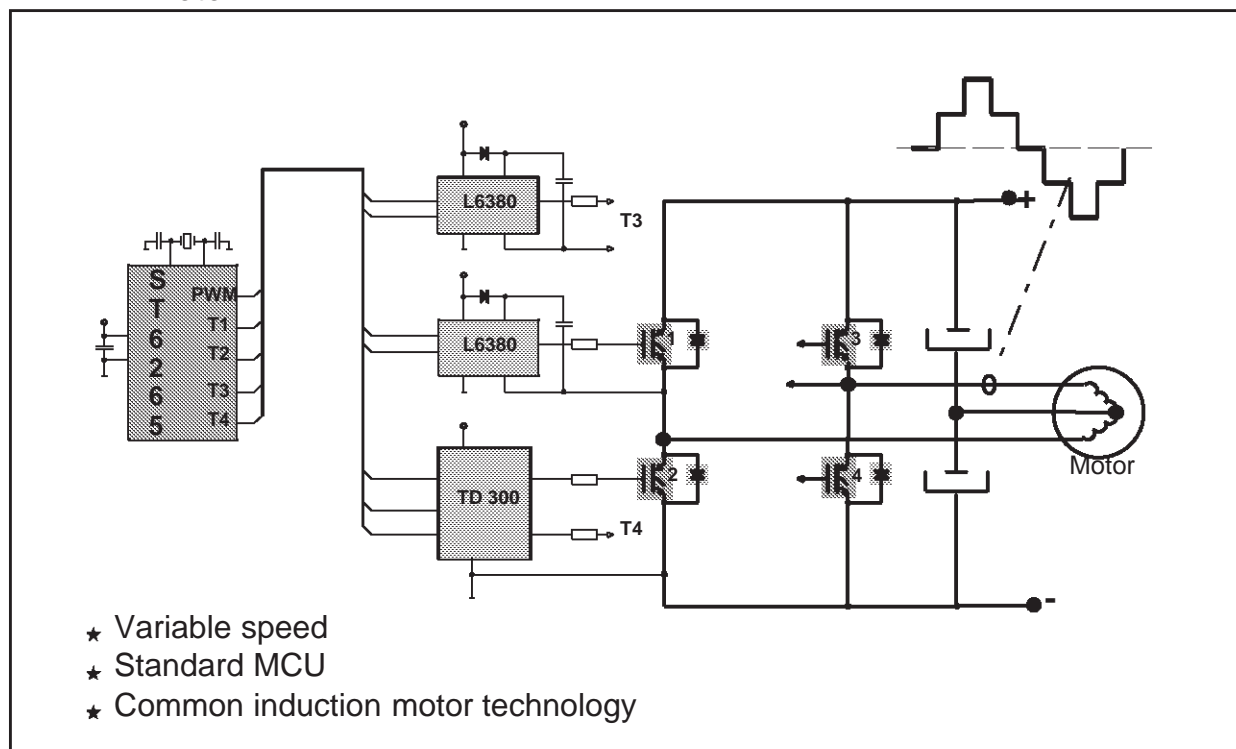
4.2 VARIABLE SPEED CONTROL FOR MONOPHASE INDUCTION MOTORS

Variable speed is obtained by supplying the induction motor with a variable frequency AC supply. An economical way of achieving this, is to use a four switch converter generating two “8-step” square wave voltages phase shifted by 90° (Figure 7.). The start-up capacitor which is normally used, is no longer necessary and the frequency (motor speed) can be adjusted over a wide range. During start-up or speed-up/ speed-down sequences, the voltage can be adapted to the frequency by the ST62 Family microcontroller, providing the motor with a much higher starting torque than is generally reached with the common “split capacitor” scheme illustrated in Figure 6.

Control of the low side transistors, which are referenced to ground, is via a dual low-side driver STMicroelectronics IC. Two high side drivers drive the floating high-side transistors.

A low cost ST62 microcontroller generates the PWM signal, using the on-chip auto-reload timer; this signal is used to adjust the motor voltage. It also produces the necessary information for sequential motor phase commutation.

Figure 7. Economical solution for variable speed control with a monophase Induction Motor

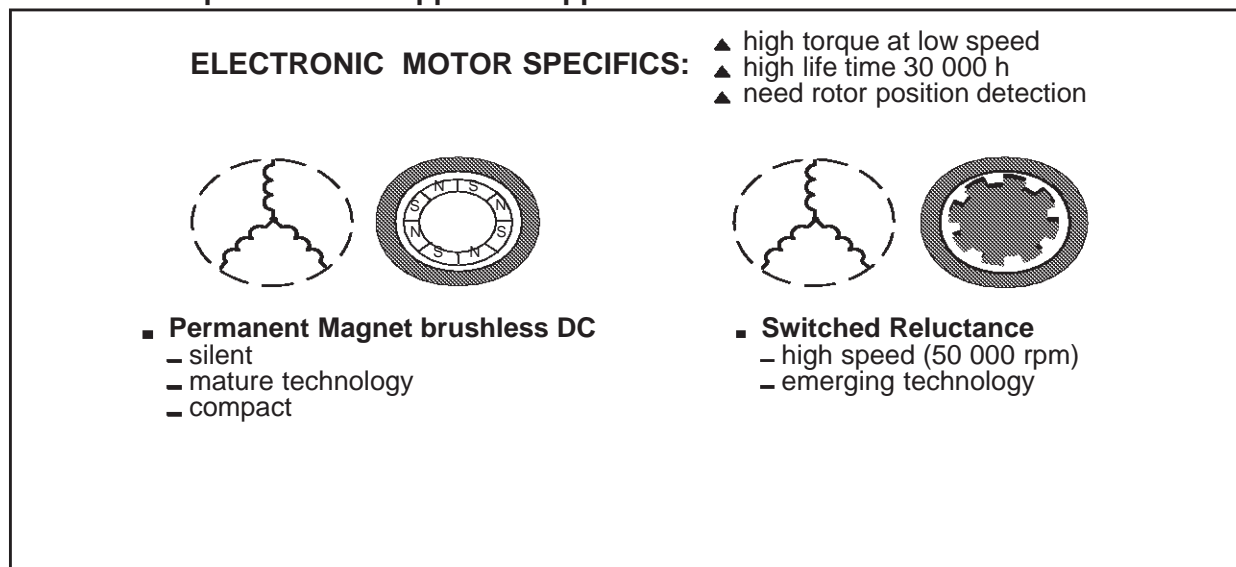


5 ELECTRONIC MOTORS

Electronic motors have no brushes and are electronically commutated (electronics replacing brushes). They offer the advantages of both variable speed and high starting torque of the universal motor, together with the absence of brushes, silence and long lifetime of the induction motor. Nevertheless, electronically commutated motors require sophisticated electronics to ensure commutation in the windings; they also require a rotor position detector.

Two basic types exist (Figure 8.):

Figure 8. Two types of electronically controlled motors which will be increasingly adopted in home appliance applications



Synchronous motors with permanent magnet (PMDC). This technology is already used in the appliance field for fans and air-conditioners, mainly in the USA. Several manufacturers are planning to use this motor type for other appliance applications.

Switched reluctance motors (SRM). Switched reluctance technology is currently re-emerging in appliance applications thanks to the rapidly falling cost of electronic control solutions. Many appliance manufacturers and research organisations are presently evaluating feasibility, characteristics and total system cost in order to define acceptable solutions.

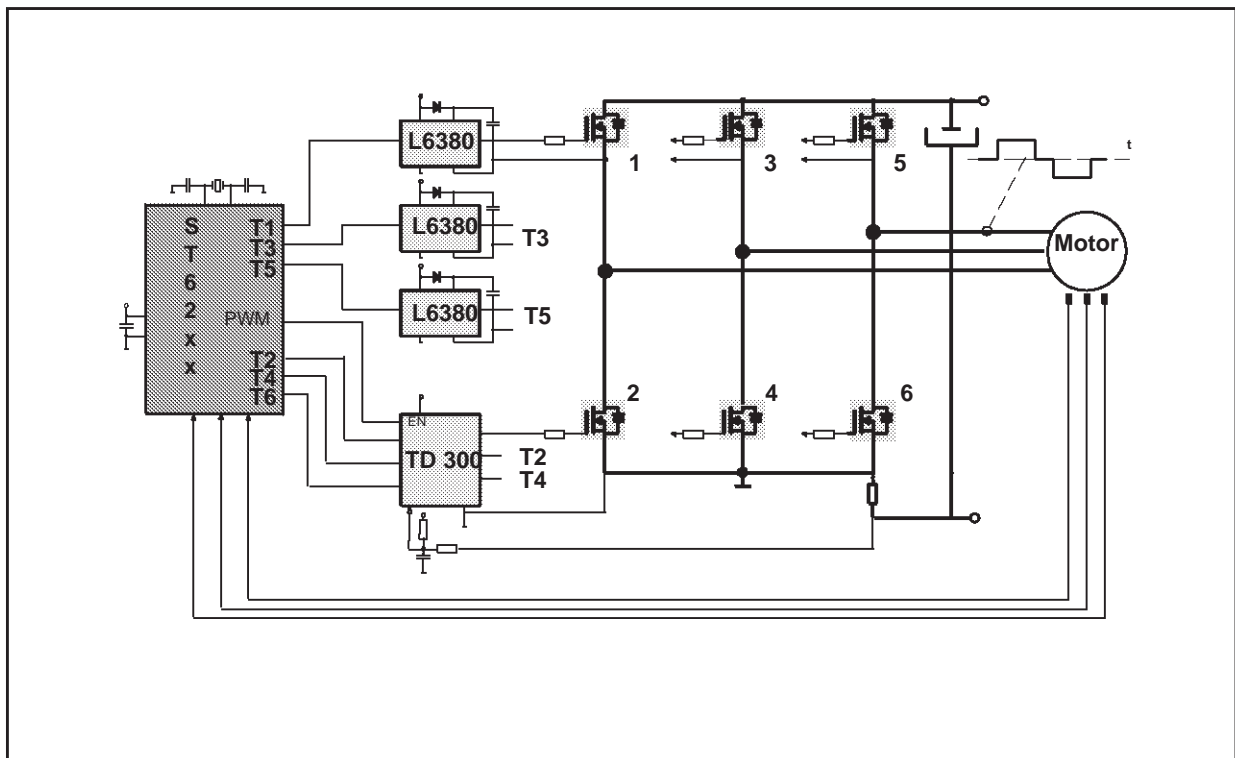
5.1 PERMANENT MAGNET SYNCHRONOUS MOTOR (PMDC)

An autocommutated permanent magnet synchronous motor is driven by a common three phase bridge, which sequentially supplies the current in the three phase motor windings in both polarities (Figure 9.).

The ST62 Family microcontroller receives rotor position information and directly controls the transistors, thus sequentially commutating the windings. The microcontroller also generates the PWM signal, controlling the voltage across the motor.

Three standard high side driver STMicroelectronics ICs (L6380) shift the ground-referred control signals to the high side floating transistors. These ICs sustain >500V and can be used in applications on 230V mains. Another standard STMicroelectronics IC (TD300), a triple low side driver, combines the phase commutation with the PWM signal for each of the three low side transistors. It also monitors the current and acts for current limitation.

Figure 9. Common triphase bridge topology with driver ICs and ST microcontroller controlling brushless PMDC motor in “6-step mode” with rotor position sensors.



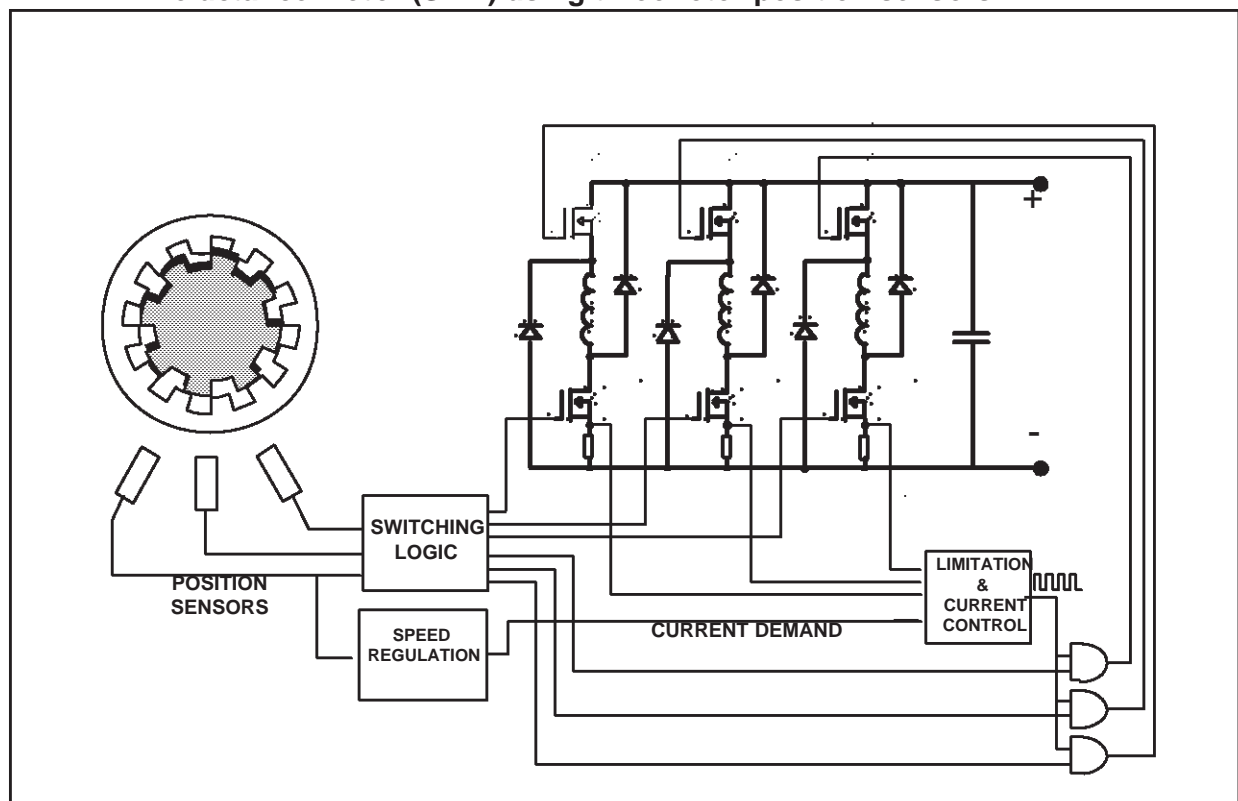
5.2 SWITCHED RELUCTANCE MOTOR (SRM)

There are various power stage topologies to drive Switched Reluctance Motors. The most common uses an asymmetrical bridge structure for each phase winding (Figure 10.).

This scheme recovers the corresponding energy in the power supply; it also authorises the overlapping of conduction phase sequences (simultaneous conduction of two adjacent phases) giving maximum torque and speed [8]. This topology is versatile and robust, as there is no risk of short circuits in the bridge-leg, because each motor winding is in series with the two leg transistors.

Usually, global control includes two control loops: the autocommutation loop, including the same number of position sensors as the number of phase windings, and the speed regulation loop adjusting current in the phase by controlling the PWM duty cycle.

Figure 10. Common topology for a triple asymmetrical bridge driving a Switched Reluctance Motor (SRM) using three rotor position sensors.



5.3 SIMPLIFIED TOPOLOGY FOR SWITCHED RELUCTANCE MOTORS

In home appliance applications, cost reduction is the major challenge. The objective is to reduce total system cost, and consequently the number of electronic components. ST62 Family MCUs make a valuable contribution in this direction, since their wide operating supply range, their built-in ruggedness, their legendary noise immunity and the wide range of available on-chip peripherals drastically reduce external component count and cost

One solution uses a single sensor. The missing sensor signals are reconstructed by the ST62 Family microcontroller, saving two sensors. The microcontroller also measures speed, executes the control algorithm, and adjusts its internal PWM duty cycle to ensure the required motor speed. [8]

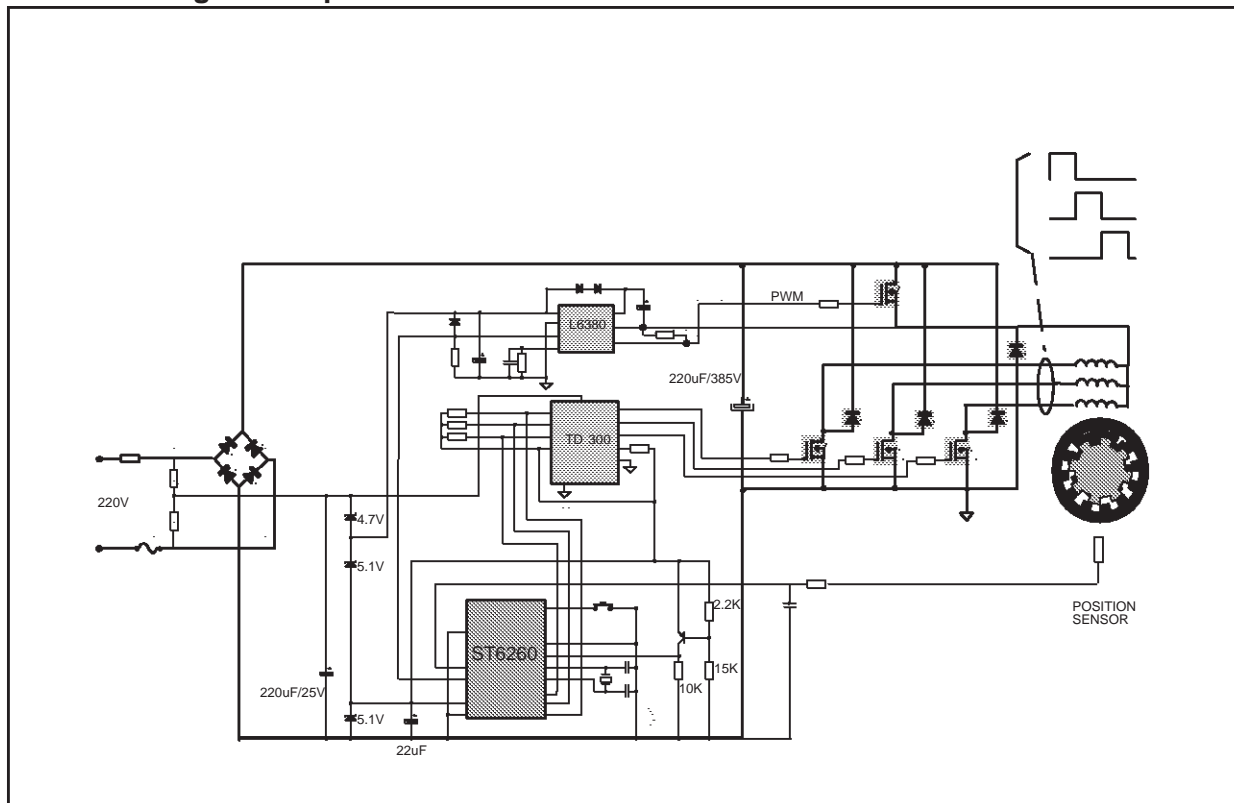
The simplified topology in Figure 11. saves two power transistors and two fast diodes. Only one high side transistor remains, adjusting (PWM) and distributing current in each phase winding when the low side transistors are successively switched.

An ST62 Family microcontroller drives the high side transistor via the L6380 high side driver IC. The three low side transistors are driven via the triple low side driver IC (TD300), which also ensures short circuit and over current protection.

The power stage includes four power MOS transistors and four fast diodes. Only the high side transistor with its associated freewheeling fast diodes are switched at high frequency, and have to be sized to carry the current of the three windings.

Each of the three low side transistors can be smaller, since they only have to switch the current of one winding at low frequency.

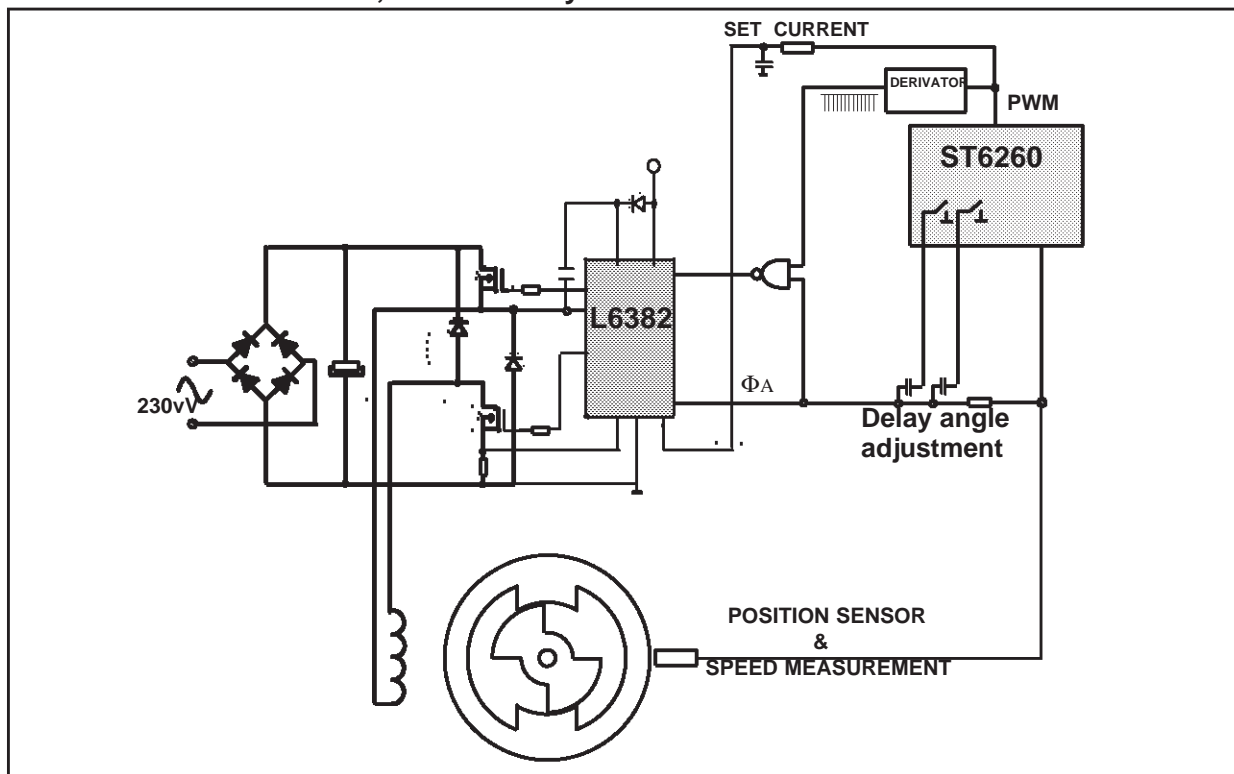
Figure 11. Simplified low cost ST62 MCU solution driving three phase SRM using a single rotor position sensor.



5.4 ST6260 OFFERS THE SIMPLEST SRM DRIVER

As an example, we can imagine an ideal SRM drive in terms of cost as shown in Figure 12. This is a single phase motor, running only at high speed, controlled by an ST62 microcontroller. The component count is low and the circuit can be assembled on an single board within the motor casing: this is an excellent example of ultra low total system cost.

Figure 12. Simplest motor drive for a single phase switched reluctance motor supplied in current mode, controlled by an ST6260 MCU



5.5 ST62: LOWEST TOTAL SYSTEM COST

The use of MCU driven electronic control systems in domestic appliance motor control will become more and more common thanks to the availability of flexible, reliable and low-cost MCUs such as STMicroelectronics ST62 Family, where the integration of powerful on-chip resources, wide operating supply voltages, built-in ruggedness and legendary noise immunity allow the designer to achieve very low total system costs.

In this way, large volume markets will be created, leading to further economies of scale and greater market penetration.

6 STMICROELECTRONICS APPLICATION NOTES

| | | |
|---|---|---------|
| [1] Microcontroller and Triacs on the 110/240V | Ph.RABIER/L.PERIER P.GUILLEMIN | A.N 392 |
| [2] Digital P.F.C with Non-Sinewave Current | /J.M CHARRETON /B.MAURICE | A.N.412 |
| [3] "Controlling a brush DC motor with an ST6265 | J.NICOLAI/T.CASTAGNET | A.N.414 |
| [4] "Sensorless Motor Drive with ST62MCU + Triac | T.CASTAGNET | A.N.416 |
| [5] "An approach to Motor Control with Fuzzy Logic | P.GUILLEMIN | A.N.419 |
| [6] "Improved Universal Motor Drive | J.M BOURGEOIS /J.M.CHARRETON/P.RAULT | AN422 |
| [7] "Versatile and Cost effective induction motor drive with digital three phase generation | B.MAURICE /J.M BOURGEOIS/B.SABY | A.N.424 |
| [8] "Simplified electronics bring the Switched-Reluctance motor to the mass market | J.NICOLAI | EPE '95 |
| [9] "PWM techniques for acoustic noise reduction in power application | J.M BOURGEOIS | AN519 |
| [10] "Inverter Design for mass production | J.M BOURGEOIS | PCIM'95 |

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