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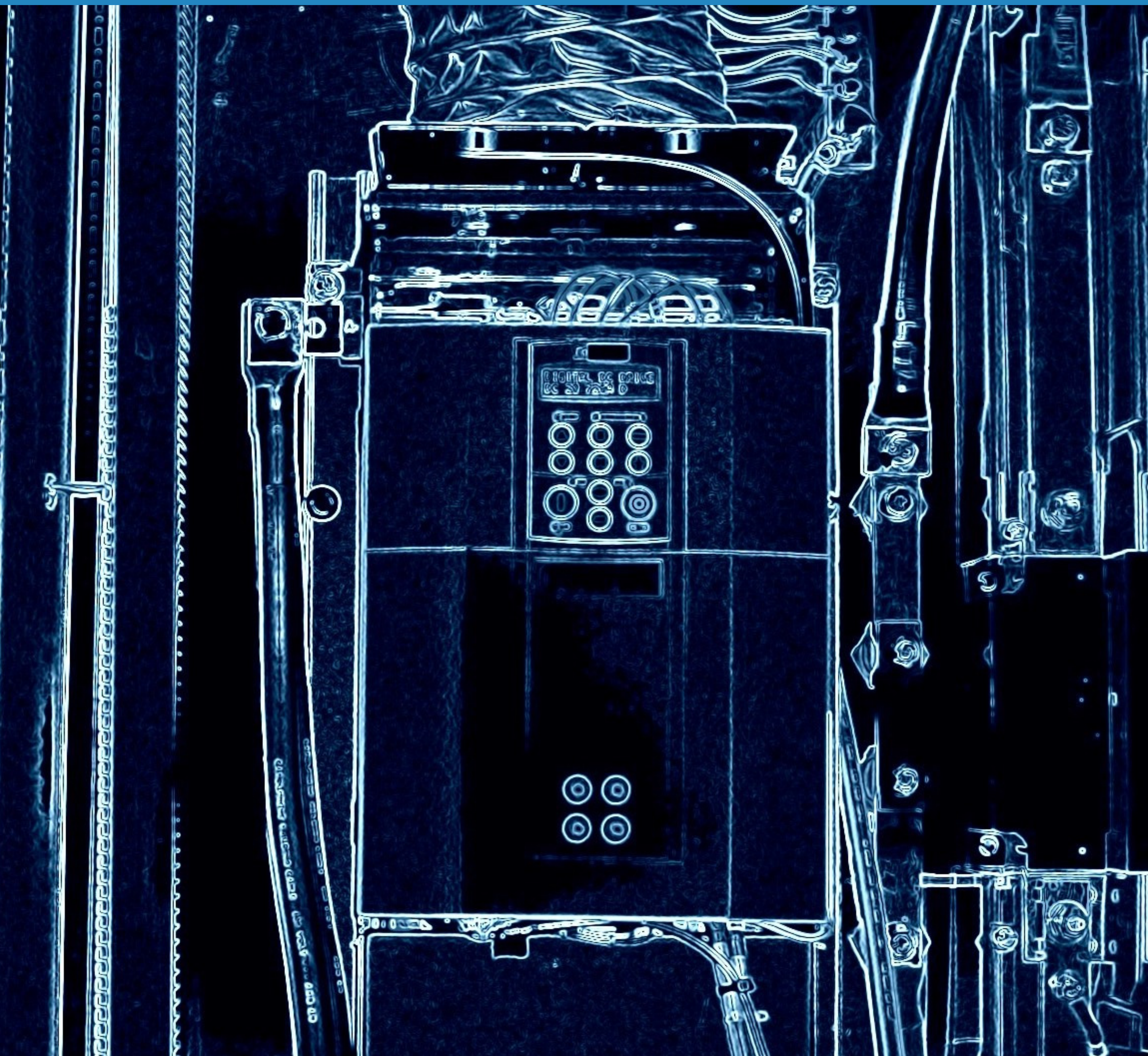
Production Line Drives: Understanding the Control System



As the automation of production processes began in the 1940s, so did the modern day industrial revolution. Subsequently, with the birth of semi-conductor technology, digital techniques and the age of programmable microprocessors an epoch of even greater significance in the world of automation is now upon us. Miniaturisation, reliability, flexibility and increased speeds are just a few of the benefits that manufacturers enjoy in this new technological age. However, the most fundamental benefit that we all get from these technologies is productivity - we produce more goods more efficiently and of higher quality than at any other time in history. Importantly, variable speed drives have always been integrated in some of the most demanding machine control situations; they remain a system critical component.

This report aims to familiarize the reader with basic but important information about two specific types of controllers – DC drives and AC drives. The first part provides descriptions of the general working principles of variable speed drive (VSD) technology. It discusses their main advantages and disadvantages between AC and DC drive solutions. The second part explains some problems that could possibly be encountered when employing AC or DC drive systems and offers practical recommendations about how to approach these problems.

Dr Adrian West, Optima’s technical director, has spent more than 30 years working with, programming and troubleshooting drive systems. This report is based on his extensive practical knowledge and experience. It is, therefore, a very accurate and independent source of information.

Variable speed drive technology

A motor is an electrical machine that produces a mechanical rotational action. It has two fundamental mechanical properties, torque and rotational speed, each controlled by the regulation of corresponding electrical components, current and voltage, in the motor's windings.

The regulation of current and voltage when controlling a motor is achieved using a variable speed drive. Essentially, this is a complex power amplifier designed specifically for the task of converting mains AC electricity to controlled electrical power components in order to control a motor.

Early drives interfaced with host control systems using inputs and outputs to which analogue and digital signals were connected using wires. These small signals interfaced (internally) with the drive's power electronics output stage. Then, as now, state-of-the-art drives were commonly applied to a very wide spectrum of applications with varying complexities and power requirements.

Control engineers design complex systems to meet specific applications that require variable speed control e.g. winders, tension control, conveyors, cranes and many, many more.

More recently, multi-processor controlled drives have permitted the use of standard industrial communications techniques and protocols to be used for signal handling in addition to the older hardwired small signal I/O and allow more detailed drive data to be transmitted to supervisory/monitoring systems. Enhanced adaptability means that more complex applications can now be resolved too and higher dynamic performance achieved.

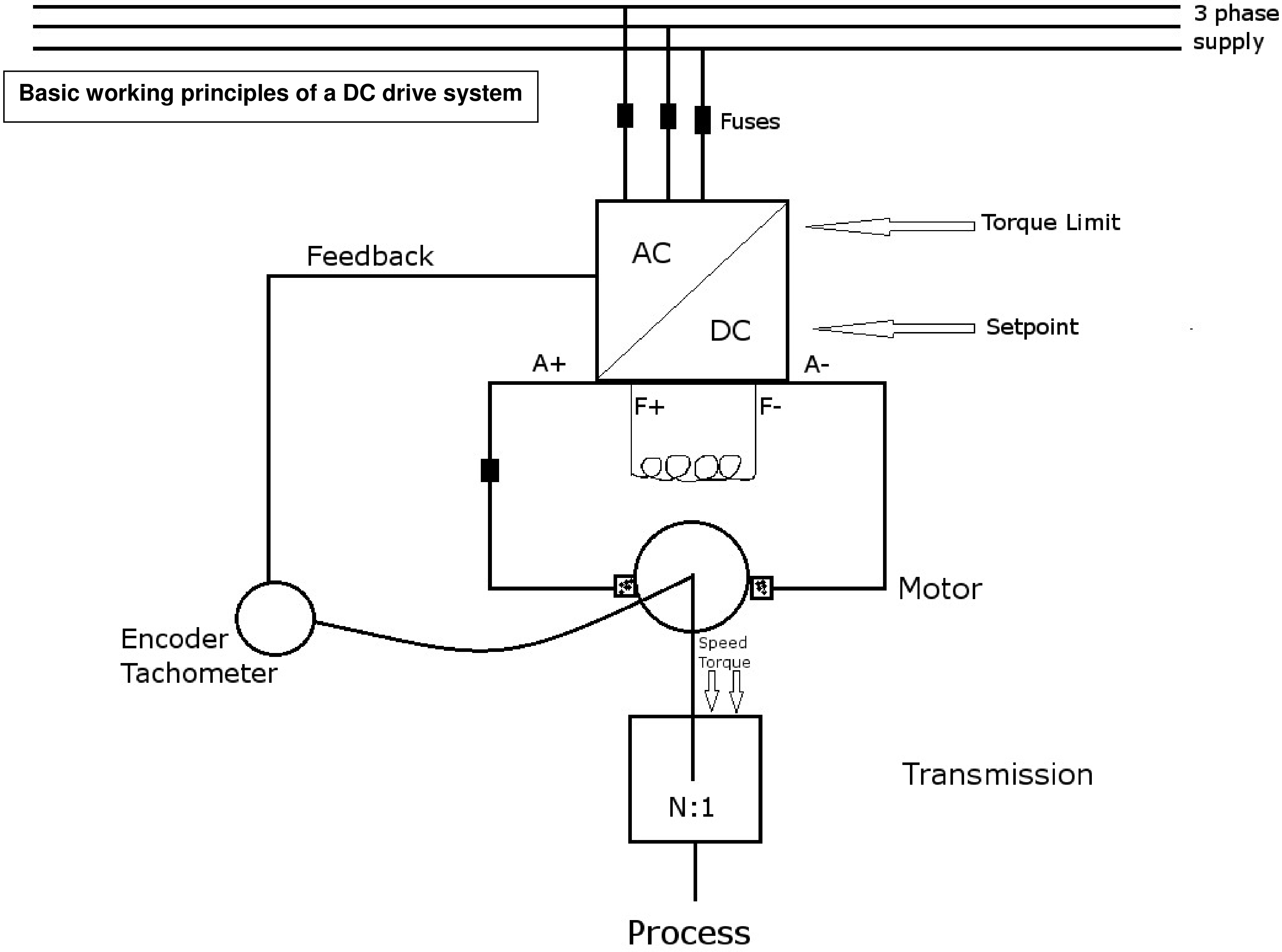
Moving on from the fundamental purpose of controlling the speed and torque of a rotating machine with a variable speed drive we can now step up our understanding of their application and consider open and closed loop control.

If an application demands a good degree of control, of either speed or torque components, the variable speed drive will need to know the actual value of the component being controlled in order to regulate it accurately as required by the application. This often dictates the use of a signal (proportional to the maximum value of the component being controlled) being fed back to the drive for use in a closed loop system (in a similar way to a driver viewing his speedometer in order to maintain a steady speed).

Without the use of a feedback signal for control purposes – the system will be less accurate and referred to as an open loop system. Some instances of more accurate control using open loop technologies rely upon accurate mathematical load models being employed to calculate the probable motor-drive performance.

In summary, variable speed drives are used as main components in the control of a vast number of complex manufacturing machine applications in virtually any and all industrial sectors.

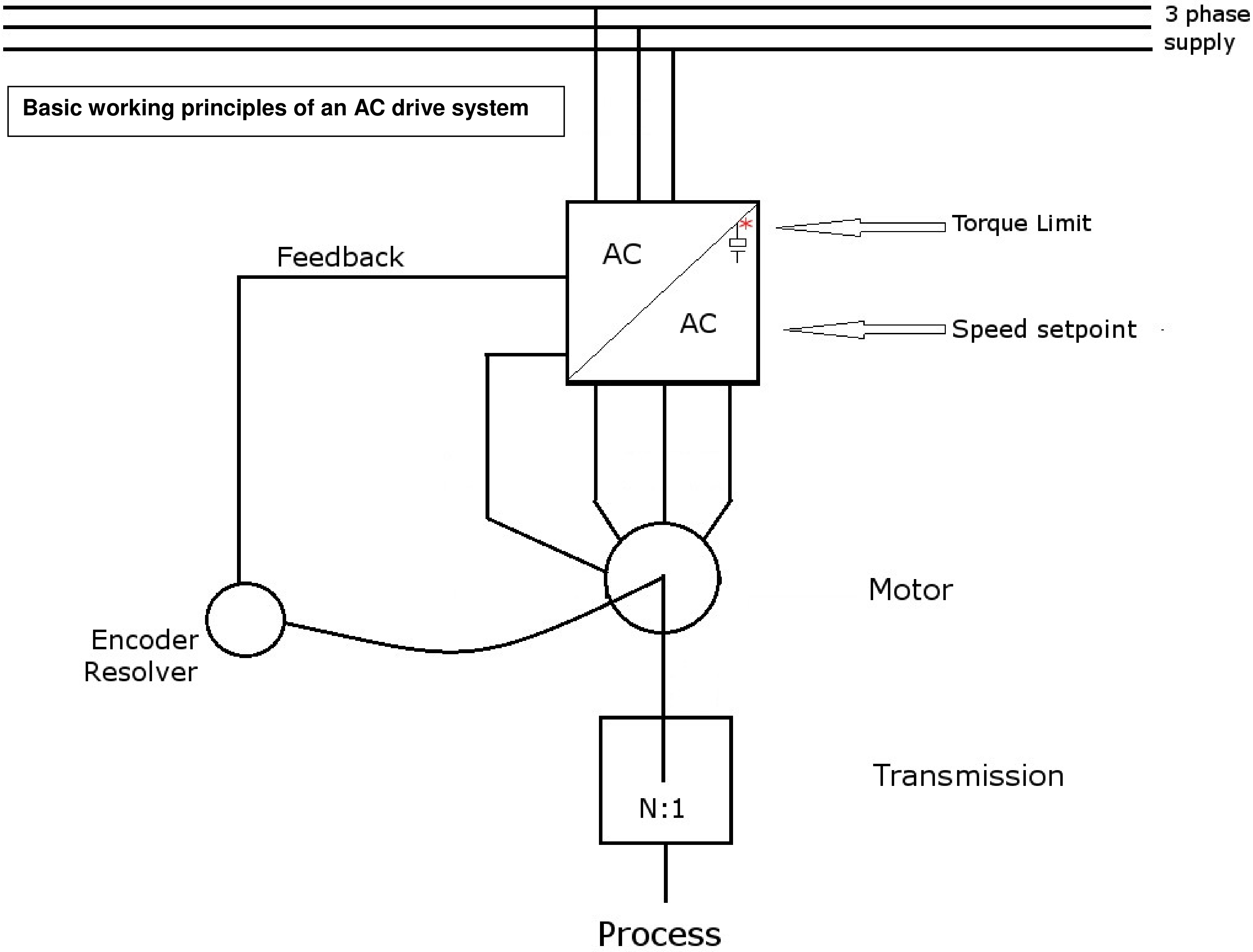
There are a number of questions to be asked when selecting which drives, AC or DC, are best suited to an application with specific advantages and disadvantages to be considered with each.



Basic working principles of a DC drive system
3 phase
supply
Fuses
Torque Limit
Setpoint
AC
DC
Feedback
A+
A-
F+
F-
Motor
Encoder
Tachometer
Speed
Torque
N:1
Transmission
Process

Technology	Advantages	Implications	Disadvantages	Implications
DC drives	DC drives are relatively simple converters.	In maintenance and trouble shooting scenarios component level repairs are possible (less so these days) This can mean a lower spares inventory requirement	DC drives have poor power factor.	Incurs cost due to inefficient use of energy and/or cost of installing PF correction hardware
	DC drives regenerate easily.	In applications with an overhauling load the excess energy produced is fed directly back into the mains supply and re-sued naturally by the process	DC drives have no tolerance for mains outage.	This intolerance means the electricity supply must be robust or any interruption will cause serious process disruption
			DC motors are mechanically complex.	They are less reliable than AC counterpart and require a more stringent maintenance regime – this carries additional overhead costs
			Wearing physical parts	Brush gear requires regular maintenance

Basic working principles of an AC drive system



Technology	Advantages:	Implications	Disadvantages	Implications
	AC motors are simple motors.	Being a much simpler construction they are more reliable than DC counterpart and require less maintenance– this carries reduced overhead costs	AC drives are more expensive due to the controller's complexity.	
	Higher performance compared to DC drives.	The lower intertia of lighter AC moors (per KW) and faster electronic power devices means that higher dynamic performance is achievable from AC drives	AC drives cannot be used as regenerators unless 2 drives are connected back-to-back.	This action is not easily achieved using AC technologies and again carries a significant cost.
	At lower KW ratings AC drives have a more breakpoints	Costs per KW are lower up to c. 25KW where after DC becomes more competitive	AC Drives technology is newer in comparison to DC	Many old machines have existing DC equipment meaning less cost to upgrade
AC drives	AC drives protect against faults on the motor.	The speed of electronic components in an AC drive allow inbuilt motor and device protection facilities		
	AC system drives can be connected to a common bus system	Energy regenerated from any bus connected drive can be used by another drive very efficiently		
	AC Drives benefit from higher IP protection rating	This mitigates the degree of special engineering needed to meet more extreme applications (wash down environments etc.)		
	Modern AC Drives are designed for close-coupled mounting	This simplifies panel design and maximises space efficiency		

AC motors use the rotating electric field principle and electromagnetic induction of a free to rotate “squirrel cage” component to generate a rotary motion. These are relatively simple electric machines. They rely however on very complex electronic power amplifiers which have only relatively recently (20yrs) been widely available since the advent of low cost, high power microprocessors.

AC drive technology comes in a number of variants, open loop (or variable frequency-variable voltage controllers). Simply – these drives output their power at a frequency and voltage level determined by to the value of input setpoint (the setpoint being derived from a small signal voltage or current source). There is no dynamic compensation applied which makes the drives prone to a degree of error.

The next level of control is similarly open loop but affords a better degree of accuracy by using accurate mathematical models of the motor being controlled. This modelling allows some prediction of the “likely” condition of the motor allowing some form of compensation to be applied.

Finally, full closed loop vector control uses very high speed processing and measured physical electro-mechanical values for the motor to control the electrical power elements and achieve very good accuracy and dynamic performance from the rotating machine for both torque and speed and achieve a much wider speed range.

The highest level of dynamic performance is achieved using servo motor technology. Used predominantly in point to point applications, this type of technology provides very high positioning accuracy, is used in closed loop systems and often employs high performance, rare-earth, permanent magnets in the motors. Designs are such now that drives and motors are paired together to get the best possible match of physical characteristics to guarantee performance.

After giving this overview of both AC and DC drive systems, Dr. West also answered a few questions regarding maintenance and problematic areas of AC/DC control solutions.

[In which industries/production lines do you see each of these variations?]

Servo motors are popular for processes that require high precision pick-and-place type positioning i.e. to move something from A to B accurately – by their nature servo equipment is high performance.

Cut-to-length machines, as another example, need this type of specialist motor to cut, say, A4 paper to the same length. Manufacturers these days design servo motors to be matched with corresponding drives.

Because even a standard full vector drive with a basic induction motor has a higher performance than a DC configuration, the market is moving away from DC. Optima have not engineered a job with a new DC motor for a long time. On the other hand, we do engineer many jobs with new AC motors/drive technology. As well as performance, AC configurations offer more advanced functionality and are generally more competitively priced. Where companies retain their DC motors, it is invariably because they have a dependable performance history that means they can avoid the expense of replacement.

[Am I right in thinking DC drives can the cheaper option but have higher motor maintenance overhead?]

You are exactly right – there is a package price for a motor and a drive At low powers the AC wins, at higher powers (say 25KW and over) DC often wins. So, there is a cross over in terms of price. Again, you have to look at the lifetime maintenance costs for an AC and a DC solution. For AC solutions, the maintenance costs are certainly lower.

[Is the choice between an AC or a DC solution ever determined by the machine itself?]

If the job we are engineering is an upgrade, we examine the existing drive scheme and assess its suitability from various points of view. As with any investments cost has to be justified against benefits, such as performance, efficiency, maintenance etc. Older machinery very often have DC control schemes. Beside the already mentioned considerations, applications that have excess regenerative energy to handle have a simpler, less expensive solution in a DC.

[In short, companies would have problems using AC drive technology to regenerate energy?]

Not exactly, AC drive technology is more than capable of regenerating excess energy, and technically speaking it offers better performance. The issue is the equipment complexity and expense. Interestingly, we are currently proposing a complex back-to-back drive configuration as the solution for an underwater wave turbine project. The turbine's function is to produce energy and as such is a purely regenerative application. Our proposed solution will regenerate energy very efficiently, it is a huge project – the cable distance between the two drives is 1 km!

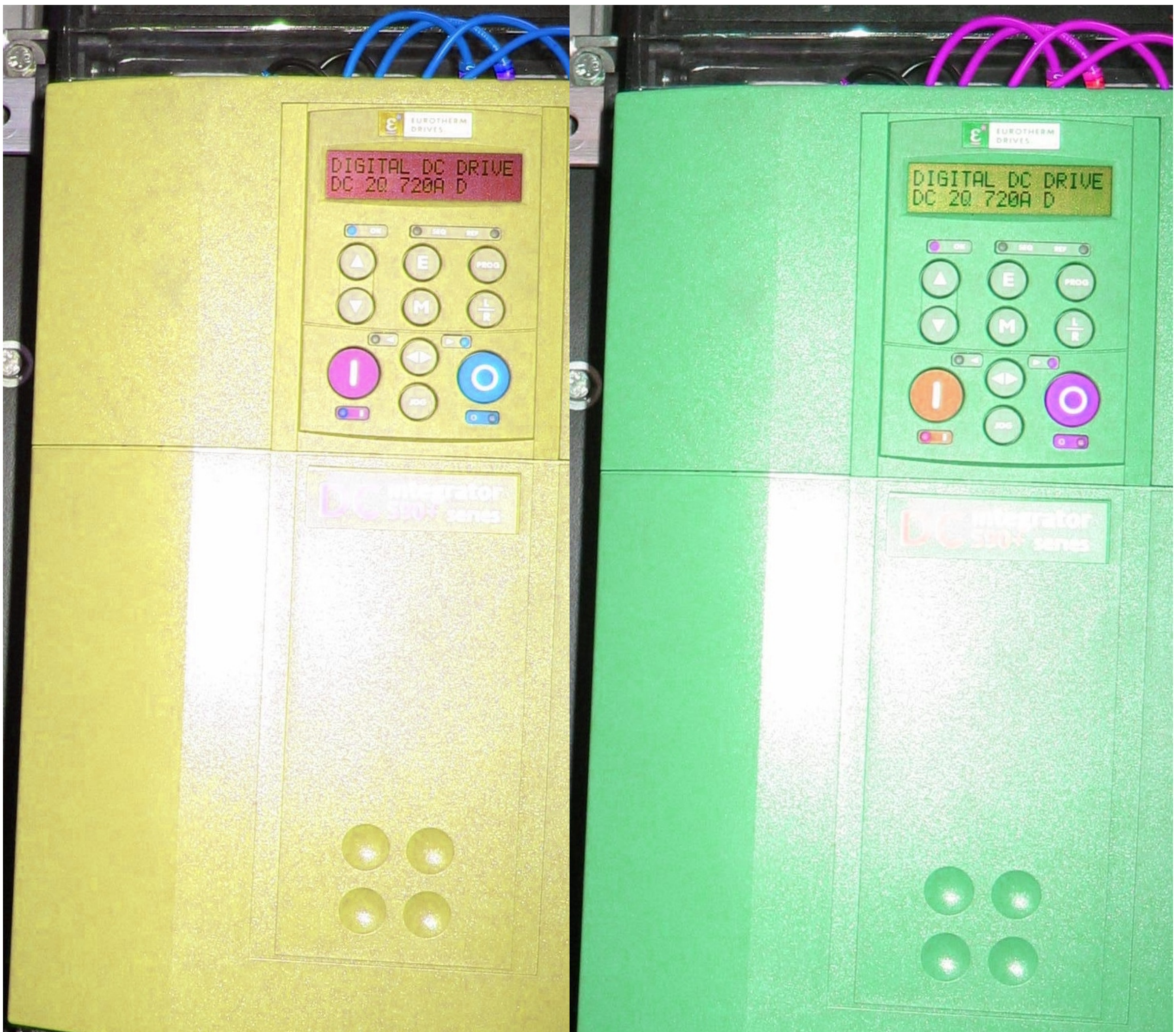
The diagram on the next page shows in more detail how regenerating energy is achieved in a machine control system.

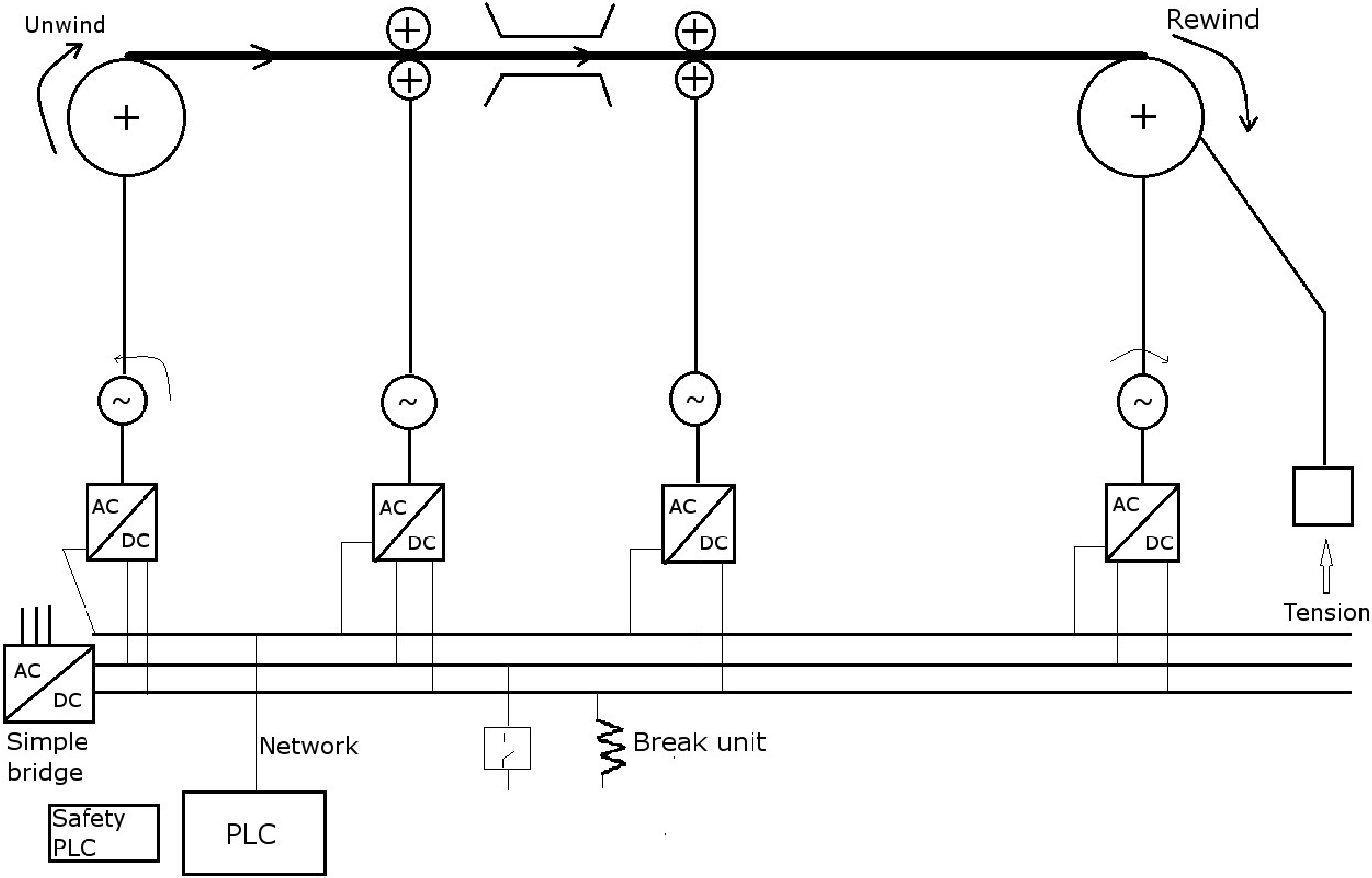
The schematic diagram describes a simple web transport system. Optima Control Solutions are specialists in this type of variable speed drive application.

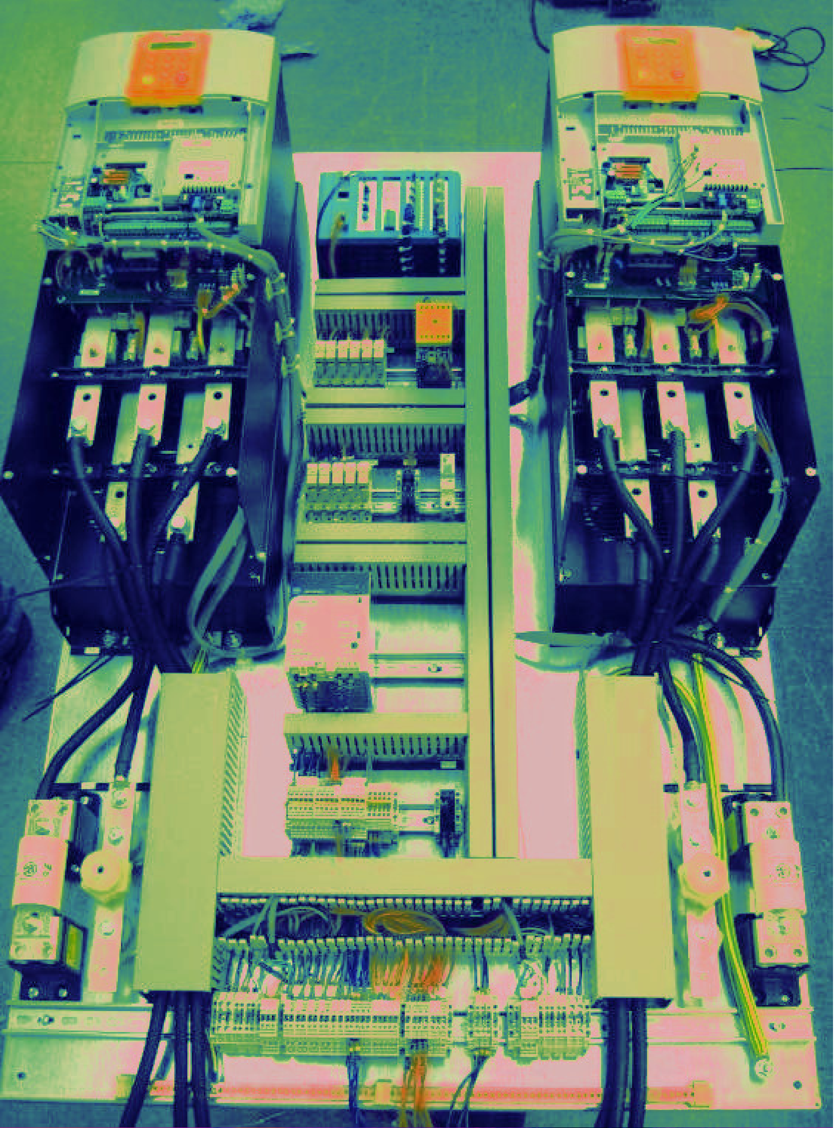
The unwind section is likely to operate regeneratively (Other section could also depending upon machine operating settings). In this case, any excess energy must be handled effectively. In most instances machines run with net power flowing in, energising the various prime movers; our wave turbine is one example where it only flows out.

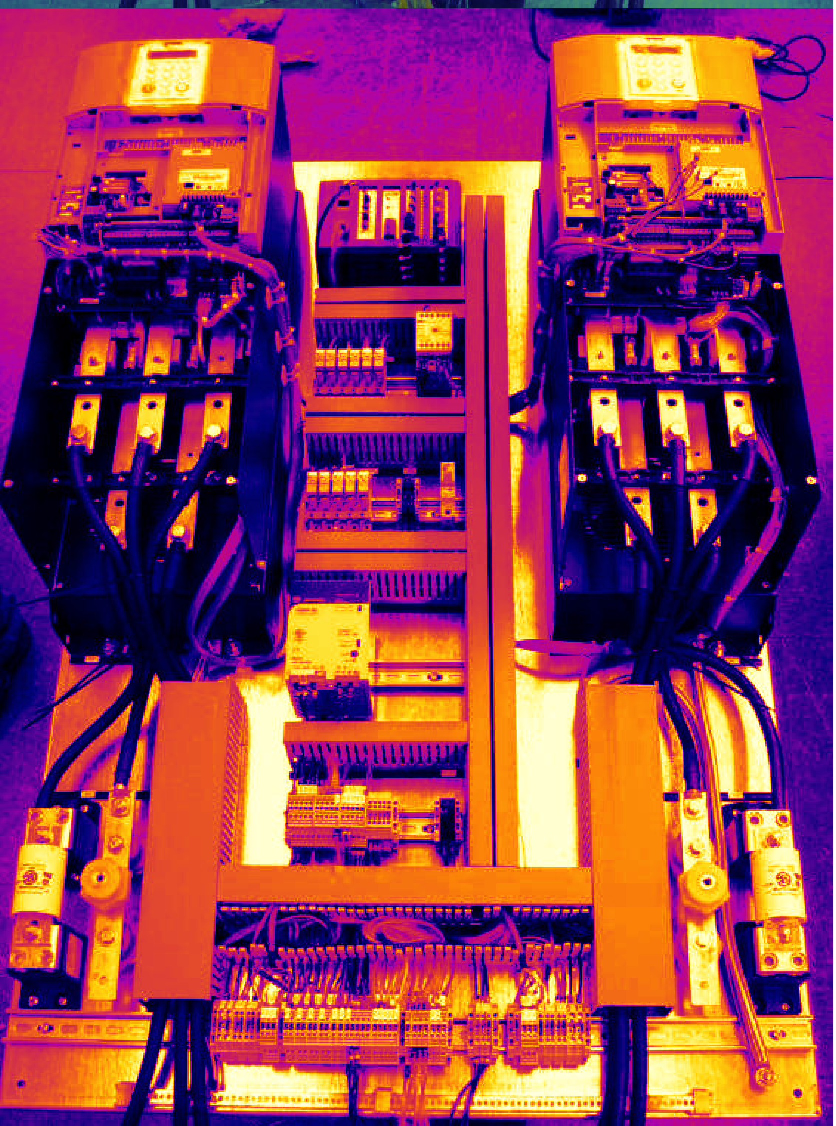
With this AC solution we couple the drives on a common DC bus. Any energy into the system is rectified from the mains using a simple bridge. The common bus allows any excess energy from any section to be fed back to the bus and consumed by other sections.

In emergency stop scenarios, where the machine needs to be stopped quickly, is is possible that too much excess energy can be generated for the bus to handle. Here the system needs a special unit that automatically routes the excess energy to a "dump" resistor. This method converts the excess energy into heat and is often a wasteful technique but is relatively low cost. The more energy efficient solution is to route excess energy on to the mains supply. This uses a more complex and expensive type of equipment whose selection is made as a result of an involved cost-benefit exercise.




Unwind
Rewind
AC
DC
AC
DC
AC
DC
AC
DC
Tension
AC
DC
Simple bridge
Network
Break unit
Safety PLC
PLC





[What are the main problems that may arise with AC and DC solutions, respectively?]

It is important to understand that AC and DC drive configurations are quite complex arrangements but these days both are generally very reliable.

DC motors have a more demanding maintenance requirement – they have more wearing components. AC motors only have bearings that wear.

DC drives are intolerant to brief mains outages. AC drives can "ride through"

AC drives have a better motor-fault diagnosis capability, for instance in-built short-circuit protection.

Issues common to both include the additional feedback devices, encoders, cooling issues etc.

[You mentioned advanced application functionality – what did you mean?]

Because micro-processors are at the heart of virtually every modern drive, most have some pretty advanced applications software loaded on them. For instance winder blocks, speed and phase lock crane control algorithms etc.

These are all complex functions that need advanced mathematical calculations to be done within the drive. You can imagine some drive applications are quite difficult to program.

Today, again because of microprocessors, drives are designed to operate on a number of communications networks so that they can 'talk' to say a PLC, SCADA or other drive controllers.

Communication systems also mean that drives can provide much more critical performance and diagnostic data to supervisory systems, improving process development, efficiency and reducing downtimes.

[Doesn't the complexity of modern drives and their applications have a detrimental effect on fault finding activities?]

Not necessarily. As I mentioned modern drives have much improved diagnostic data systems, these actually improve fault resolution times. There is a well know adage that "software wears-in over time, mechanics wear-out". That means that once software is commissioned and working, as time passes, the most likely cause of problems would be due to electro mechanical causes or wiring faults.

After the software is debugged it is pretty reliable for a long time. Mechanical faults often manifest themselves in the control system but, engineers find the problems elsewhere.

There is something called the bathtub failure of electronics ***(see the picture above).*** This curve describes the likelihood of a fault occurring over the lifetime of a product. You can see that after a few months of its working life, the equipment is pretty reliable. So, if your equipment is at this flat section of the bathtub curve, the control system will be quite reliable.

[What period of time does the bathtub curve span in a control system example?]

Typically about 10 – 20 years. There are control systems out there that I know about that were designed in the 80s and they are still running but it is not unusual for the period to be as short as 10 years.

Often, you will find that a machine manufacturer will give you a guaranteed supply of machine spares for 10 years. But, if during that period a control equipment manufacturer is about to make their product obsolete, you could be in a bit of trouble and should plan to change the controllers even if they are still operational. E-bay is not a reliable spare parts resource!

It's worth mentioning a known potential issue with AC drives which use important components called capacitors. These use a liquid electrolyte in their operation, which over time can make them vulnerable to failure. This is because, if their host drive runs at high temperatures, the liquid electrolyte can dry out and stop working. It is not unreasonable for a drive to run at high temperature so this scenario developing over a 10-year period is not uncommon. You can see that an AC drive probably will not last as long as a DC drive which doesn't use high power capacitors.

That's probably explains why the 30-year-old control system I referred to is still running well - it had DC drive technology.

[To move on to example failure modes, what parts would you check if a motor was overheating?]

Overheating is very often a result of either poor cooling, e.g. fans and filters being blocked, or motor overloading due to the process being run incorrectly e.g. running with too much tension (perhaps due to wrongly calibrated load cells), this will overload a motor.

It is important to note that in general, a drive, AC or DC, would protect against over temperature anyway. There is a sensor in the motor that gets feedback into the drive and it warns you and shuts down before the motor is damaged. Also, the drive will often not allow you to overload through torque or current limit features, so overheating may result from lack of cooling, so as I mentioned earlier, a fault could either be in the motor itself or in the cooling system.

[What is it that Optima knows about drives that others do not?]

That's a trade secret! *[laughs]* We are really skilled in programming drives - but it is *not* writing software that is at the root of our expertise – it is our understanding of a whole control system, including the mechanical components, the materials being processed, their characteristics and with all variables considered we make drives perform well in each application. Not many people are able to do that!

Many control companies feel comfortable programming PLCs, SCADA and engineering networks, but understanding how to write the algorithms in the drive itself is a complicated task. It is something you will never be taught at a university, it must be learned through experience.

The work we do is often perceived as high-risk; by our customers as well as competitors. We recently engineered the upgrade of a coater line for Tullis Russel in Scotland? It comprised over 90 VSDs and physically it is bigger than a terrace of houses – not too many companies would tackle something of that scale. It is, however, what we are good at – whatever the production process, we are confident we can achieve the desired result which often save our clients vast sums of money when the alternative is a new machine.

Obviously major drives manufacturers have similar resources to us, but as large multinationals they have to charge more to cover their overheads.

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