New Automatic Voltage Control Designs for Enhanced ESP Systems Integration, Improved Reliability, Safety and Troubleshooting Capabilities

John Comer, Royce Warnick, Mike Volker, Jason Horn
(Stock Equipment Company, Inc. 16490 Chillicothe Road. Chagrin Falls, Ohio 44023-4398)

Abstract: Modern high speed microprocessors, advanced display technologies and recently developed circuit protection components have allowed a new generation of ESP controls to be developed. This paper reviews the advances made and how they impact users. Specifics of the designs will be shown and described along with real-world examples of their application. A discussion of the rational behind features such a "Closed Door" troubleshooting, and multi-language support will be discussed. Closed Door troubleshooting is critical to minimize the risk of Arc-Flash injuries. Multi-Language support is becoming a requirement to ensure that the controls are setup and used properly wherever they are installed. Both of these requirements put demands on the electronics and display technologies which drive the choice of components and support circuitry. A description of the design trade-offs made during the development process will be included. Field experience with the new design, reliability statistics and plans for future development will complete the presentation.

Keywords: Voltage Control, ESP, review

1 HISTORY

The history of AVC technology in some ways mirrors the advances in ESP design improvements. Early (1960's through 1970's) ESP's incorporated collecting electrode spacing of ±9″ (228 mm), yielding a discharge electrode-to-collecting electrode spacing of ± 4.5″ which was in keeping with the nominal 45 kV average output Transformer/Rectifier sets available in that generation. The earliest TR sets utilized tube-type rectifiers and had little more than a rheostat for control. Spark response was an after thought and power control was performed manually.

Later in the 1960's TR sets utilizing solid state components, in conjunction with saturable core reactors were employed along with the first "solid state" automatic voltage controls. These devices advertised spark response capability but it's detection and response speed was, by today's standards, the equivalent of reading a newspaper from 2004 and considering ones self up-to-speed on current events. In short, once the spark or arc was detected and a response action taken, the damage, sometimes substantial, had been done. The 1970's brought anti-parallel thyristors (SCR's) into the control scheme for ESP's along with AVC components that were substantially faster and more precise than the saturable core reactor technology of the previous decades. The saturable core devices were replaced in the circuit by current limiting reactors (CLR's) often referred to in the business as linear reactors. The devices served as a choke or "shock absorber" for the energy surges in the circuit resulting from spark events and the subsequent increases and decreases in power. Later, when collecting plate spacing increased to 12″ (300 mm) these improvements were even more important due to the increased energy required in the system to insure that particles would migrate over a span of 6″ from the ionization source to the ground potential as opposed to 4.5″ in earlier designs.

These controls were capable of, at least sometimes, sensing a spark within the cycle it occurred and prompting a reduction in power to prevent it from actually getting worse. This generation of controls was the first to use process control phrasing such as "phase-back", "ramp rate", and "quench" which defined the response the control would take to a spark event and the speed at which it would try and implement the response. As stated previously, these controls were substantially more effective at their mission but, because they were prone to "drift", they were still incredibly difficult to calibrate and the values that were dialed in one day would be completely inappropriate, and sometimes damaging, the next.

As the 1980's were ushered in, first generation microprocessor based controls were becoming available from nearly all of the traditional OEM ESP suppliers. Aftermarket suppliers, FORRY among them, first introduced products for ESP voltage and rapper controls on a widespread basis early in the 1980's. The aftermarket suppliers had the advantage of operating their businesses without the extremely high engineering and staff head count burden that the OEM's did while being able to focus their talents on just the control of these two important subsets, i.e. voltage control and rapping, of precipitation. These entities could supply a higher quality control, at a lower price than their OEM counterparts specifically because, in many cases, it was all they did. Coincidently, the personal computer business evolved in a similar fashion during that same time period. Business giant IBM fancied themselves as a hardware company that was perfectly content to leave the operating system and software application side to upstart, garage-based companies like Microsoft. Similarly, ESP performance was enhanced greatly from these new controller offerings because their inventors were cutting edge people, focused only on electronics and innovation, that did not have to concern themselves with ESP sizing and risks associated with particulate performance guarantees that occupied the minds of the OEM's continuously.

Again paralleling the computer industry, advances in microprocessor speed and memory capacity leapfrogged earlier versions on what, at that time, appeared to be an annual basis. While the AVC market did not update at the speed of the chip providers, product improvements were rapid and, in most cases ESP performance benefited.

Into the 1990's and beyond, the ESP control systems were "mated" with PC's for operation and data logging as well as central control system architecture from various suppliers. These DCS (distributed control systems) were employed to integrate a wide variety of subsystems used in a wide variety of process industries including power generation, cement manufacturing, steel making, petrochemical refining and others. These systems put the "global" control of the discreet field devices into the hands of operating personnel in a way that had never been possible before. The challenge to end users during this period came from growing commercial pressures to do more with less and spend less doing it! Staff reductions meant there were fewer ESP specialists to tend to the new electronics and, in general, monitor the precipitator. Companies looked to technology as a way to save energy costs, i.e. energy management systems, which ESP control suppliers employed to reduce precipitator energy consumption while maintaining particulate removal efficiency. Subsequent changes in environmental policy in many parts of the world have reduced the possible applications for this feature but it is still used in many industries and to good effect.

2 INTRODUCTION

Today's ESP operational environment provides many more challenges for designers and manufacturers of ESP control systems. During the 1960's and 1970's when ESP technology was gaining widespread acceptance, controls simply had to maintain 'design' performance while at 'design' operating conditions with 'design' fuels. This would be a dream application in todays "new normal" of off-spec fuels, substantially increased flue gas volumes and extended runs between scheduled maintenance outages. However, it is quite fortunate that the incredibly challenging environment of today has waited until today to arrive! If a vintage analog or first generation digital control was subjected to todays conditions, the performance of most ESP's would be less than satisfactory! In addition, there are many more reporting, co-ordination and increasingly safety related requirements which a modern automatic voltage control must be able to comply with in order to be accepted by the end user community.

Since the mid-1980's, the available electronics and microprocessor technology has allowed designers of Automatic Voltage Control (AVC) systems to offer successive generations of controls, each with considerable increases in performance, reliability and flexibility. Today's AVC is approaching a point where performance has been optimized as much as the fundamental power supply components (SCR's, CLR's and Conventional line frequency Transformer-Rectifier Sets) will allow. However, while the rate of improvements in raw performance enhancements between AVC generations may be slowing down, the controls are now making leaps and bounds in terms of usability, reliability and easing compliance with both safety and regulatory reporting requirements. The Latest Forry™ Brand AVC's are actually 5^{th} generation devices which are using modern, current generation 32 bit microcontrollers and DSP chips. These components and others, have advanced in their capabilities even more quickly than the demands of the control application have increased. This, in turn has allowed system designers to include a wealth of diagnostic, ease of use, reporting and reliability features in each new generation of control.

As an example, the AVC•XM, today's current Forry™ Brand control offering, has over 60 times the primary processing power of the previous generation of Forry™ Brand AVC, the AVC 9000. This allows for a much more user friendly interface, more precise control algorithms, much more accurate calculations of operating parameters, diagnostics such as on screen long term trending of operating parameters and on-screen high resolution waveform displays and greatly improved reporting functions via higher speed and higher reliability communications systems.

3 GENERATION 5 CONTROL HIGHLIGHTS

When compared with the last generation of Forry™ AVC controls or for that matter pretty much any manufacturer's mid 90's release AVC's (Generation 4 Controls) the differences are dramatic and the benefits to ESP operators are tangible.

3.1 User Interface - Settings and Control Interface

Typical Generation 4 systems utilized monochrome text or extremely rudimentary graphical display technology. The amount of information presented to the end user by these Generation 4 controls was very limited. These earlier controls usually made due with a 4 line by 40 character text display for all feedback from the control to the local users. Currently available terminal technology allows us to provide a full color 3.8″ screen which provides extensive diagnostic reports and graphical representation of both current system operation as well as up to 7 days of historical data.

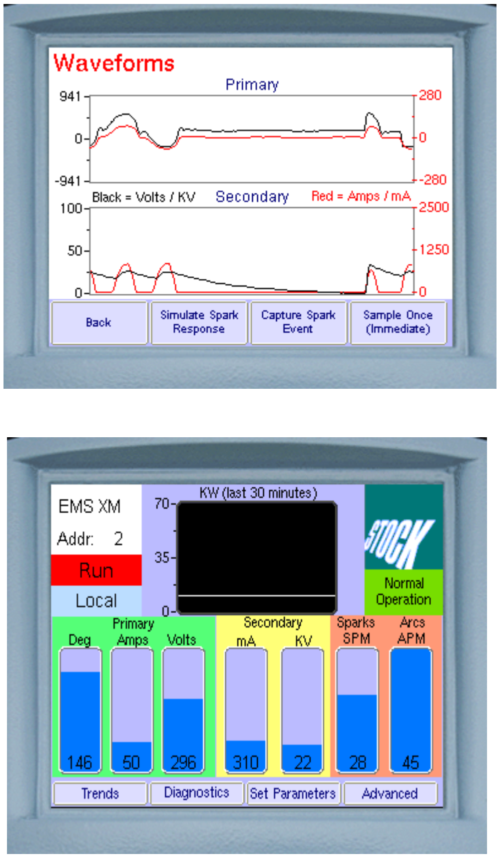


Fig. 1 & 2 Screen Captures from the AVC XM Hand Terminal Main Screen and Waveform display pages

3.2 User Interface - Operating Parameters

Many earlier generation voltage controls simply utilized analog meters for the 4 key electrical readings of each TR set. While this approach has great intrinsic value, (nothing beats watching the twitch and swing of the needles when trying to diagnose mechanical stability issues in the ESP.) The latest generation of controls utilizes bright LED based displays which indicate what state the control is operating in, all critical parameters in 1" high digits readable even in direct sunlight. These displays can be read from across a large room and clearly indicate if the control is in a current or voltage limited condition.

3.3 Communications' Speed and Reliability

In the United States, Federal and State Title IV reporting requirements have necessitated the need for all voltage controls to regularly report and log their operating parameters. While many older, Generation 3 and 4, voltage controls provided the ability to communicate with a central computer or DCS Data Historian, very few of the fielded systems achieved reporting reliability standards that made State and Federal regulators comfortable.

Fig. 3 New AVC XM Cabinets with optional Flush Mounted Displays. Note the analog meters are still best practice for certain troubleshooting techniques.

This stems from the extreme electrical interference conditions that exist within the controller cabinets as well as the generally rough service that any electronic device is subjected to in the power plant environment (high/low temperatures, vibration, extreme "fan killing" levels of abrasive coal dust and ash as well as extremely poor power quality) Once again, careful design of the AVC and the availability of communications drivers hardened for the extreme testing conditions encountered to achieve "CE" marking allowing sale of the products in the European Union have allowed the Generation 5 controllers to be dramatically more reliable than even the best examples of the previous vintage.

4 MORE ACCURATE WAVEFORMS AND POWER CALCULATION

Because of the higher processor speeds and extremely accurate analog to digital convertor available in our latest generation design, we have the ability to sample each analog signal in the AVC 16 times as fast as we did in the last generation of controls. Additionally, we have a dramatically improved noise filtering and suppression circuit which results in the cleanest secondary current and voltage signals possible outside a research lab. What this means to the end user is that spark discrimination is virtually flawless and the waveforms provided on the terminal and PC user interface are nearly as accurate as those produced by a typical oscilloscope.

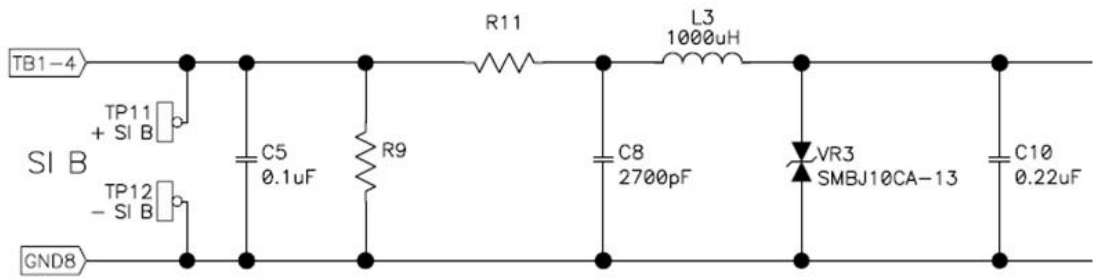


Fig. 4 AVC•XM Secondary Current Filtering and Surge Suppression Circuit

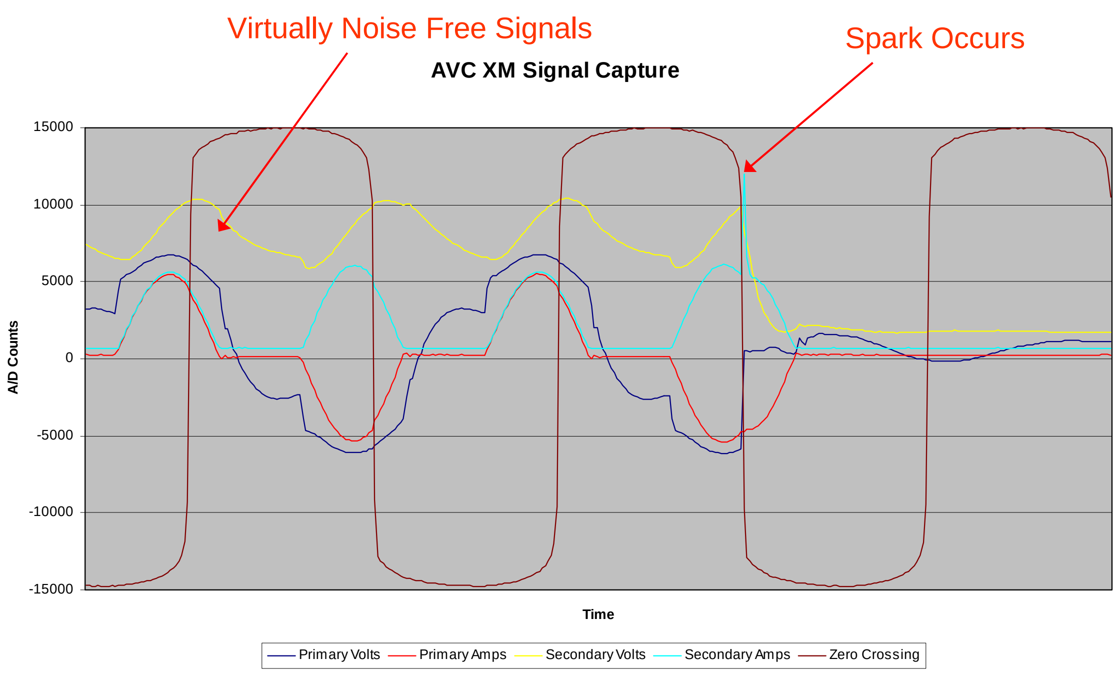


Fig. 5 AVC•XM Unsmoothed or Filtered analog signal capture (Raw A/D counts)

Only 1 User Configurable Hardware Jumper

Other than a jumper to force the AVC•XM to emulate the communications protocols of our previous generation of controls there are no adjustments that can be made to the actual controller circuit boards. This, combined with the high accuracy, extremely low drift analog sampling circuitry means that virtually all troubleshooting of the ESP power supply system can be accomplished via the AVC•XM hand terminal while the control cubicle door remains closed. Thus permitting technicians to avoid working in heavy and extremely cumbersome arc-flash protecting hoods gloves and other protective gear while attempting to position tiny probes on a circuit board in a dark and electrically live cabinet!

So, what does all this technology mean to the end users? Our design goal when developing the controller was to develop and commercialize a state of the art Automatic Voltage Controller which set new benchmarks for performance, reliability and especially ease of use.

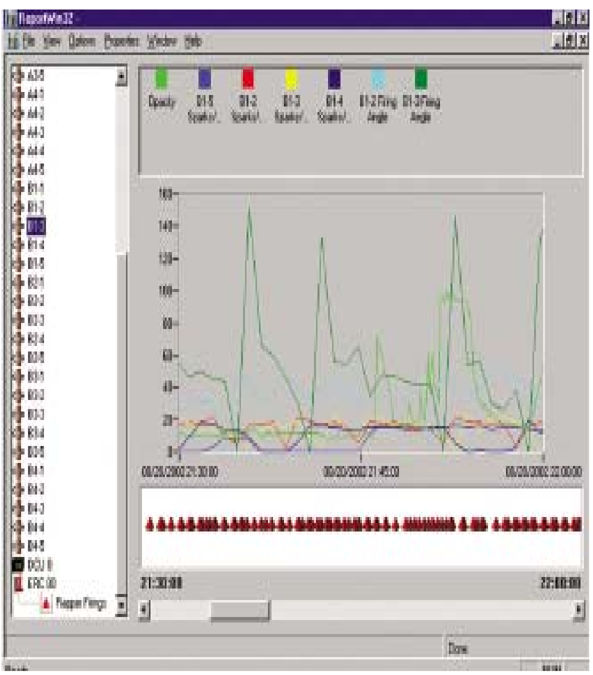
Early on in the development process, the development team created what is known as a Product Concept Statement: “A Simple (operator trained in <10 minutes), Highly Reliable and Low Cost Automatic Voltage Control that is compatible with the large installed base of Forry Control Systems and provides improved functionality and enhanced features to improve performance and simplify troubleshooting.”

Based on performance and reliability data gained during the first two years of installations since the product was released we believe that the AVC•XM has met these goals and is positioned to provide many years of service to the air pollution control industry. Almost 600 controllers have been installed in the field, and as of our latest count only 2 had experienced failures in service. This represents a failure rate at least 90% lower than our last generation of controller.

When moving to 5th Generation controls, customers should experience simpler setup of the AVC's, much easier, more accurate and less frequent calibrations. And far fewer in service failures of the controllers. The bottom line is that the latest generation of controllers provides valuable and substantial and gains in performance, ease of use, safety and reliability.

5 INTEGRATION ADVANCEMENTS

Advances in microprocessors allow end-users to take advantage of intra-device communication and coordination in a way that was not possible in non-DSP based control systems. Voltage controls of 8 & 16 bit capability that were integr were forced to siphon off processor power for integration and tasks that reduced the performance of its primary purpose, i.e. spark & arc detection and response. Large or complex systems would inevitably experience issues in communication, control algorithms, or both when trying to "talk" to each other and perform a specific task.



Rapper control integration can be especially tasking on systems typical of power generation ESP's that can easily have 400 rappers or more per precipitator. In addition, today's FORRY rapper control, along with some others, is capable of performing many discreet and global control functions down to the level of **individual** rapper intensity adjustment on **every** rapper. Likewise, AVC's and rapper controls must coordinate power application properties vs. rapping frequency and intensity to keep today's ESP's clean but in compliance with emissions regulations at all times.

At FORRY we actually employ 2 processors in our XM AVC. The main DSP processor monitors conditions "inside" the ESP, principally spark & arc detection and response. An additional "ColdFire" processor supervises the intra-system communication and data logging/historian functions without taxing the capabilities of the system processor.

In this way, the AVC's can work in concert to perform Power Down and Power Off rapping functions that maximize cleaning effectiveness while keeping ESP field power suppressed or off for very small amounts of time, i.e. fast enough to eliminate upsets out of the stack while cleaning the internals enough to support better power introduction than existed before the cleaning process was implemented.

Other advances in system configuration allow the cause & effect relationship of discreet rapper operations and their effect on Stack opacity to be tracked in real time. The FORRY system will monitor discreet rapper operation and compare it with an opacity signal fed into the control in real time. This Rapper Tracker feature allows users to discreetly adjust rapper timing, intensity or both to "smooth out" the rapping puffs that are, by nature, a common occurrence in precipitators. Example shown below:

In the example, the triangular rapper "icons" are shown in operating order directly below the green opacity trace in real time. Rolling the PC mouse over the rapper identifies its name, and location allowing the user to track and adjust those individual or groups of rappers that result in "puffing" when they operate. In much the same way, ESP energy consumption is controlled via feedback to the system that monitors process output and emissions and adjusts the AVC's to apply suitable power to the ESP for maintaining compliance without wasting power due to unnecessary ionization. An example of an energy evaluation and payback prediction is shown in the illustration below for a six field flyash precipitator:

Field	Pri Volts	Pri. Amps	Sec. Ma	kV	Sparks/Min
1	260	32/68	190/500	42/55	0
2	210	21/68	120/500	35/55	0
3	375	64/68	450/500	42/55	0
4	400	80/102	580/750	41/55	0
5	370	75/102	600/750	40/55	0
6	500	82/102	620/750	40/55	0
7	420	86/102	580/750	40/55	0
8	440	85/102	610/750	44/55	0

Values are shown with actual vs. nameplate for each of the transformer rectifier sets, all of which were in service during the visit. Fields 1-3 are 39 KVA power supplies, fields 4-8 are 59 kVA.

Total Current Consumption – 525 AAC

Total kW – 195.2 kW

Given that there was **no** sparking in the ESP at a low opacity, it is safe to assume that a reduction of 50% in primary current, across the board, is achievable.

The energy recovery calculation includes:

kW total × .50 %(reduction) × .85 (p.f.) × 8000 (op. hours/yr.) × MW cost (not value)

195 kW × .50 = 98 kW × .85 = .083 MWh × 8000 = 664 MWh × $24 = $23240 annually.

A point that must be remembered is that, during periods of lucrative power sales or in the case of expensive power purchasing, the recovery value can expand exponentially over a very short period of time as is illustrated below.

195 kW × .50 = 98 kW × .85 = .083 MWh × *800* = 66.4 MWh × *$400* = $26,560 annually.

Suffice to say, either energy recovery scenario would yield a payback that makes excellent sense.