Energy Storage for Industrial Processes

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Abstract

Electric power quality has become an economic issue with end-users. Poor power quality can destroy the competitiveness of a company, especially companies in industries with thin margins.

Electric end-users have a broad definition of power quality. Most would agree, though, that good power quality is a level of electric service that provides the necessary power parameters to keep their process line operating. Those parameters can be reduced by electrical events that occur normally on electrical systems. Those events could range from subcycle impulses to multi-cycle voltage sags to temporary outages lasting 20 seconds. Impulses and weak voltage sags are aberrations that can usually be mitigated in a cost-effective manner. But, when a one-second or greater outage occurs, power quality mitigation becomes expensive, if not impossible.

The Flywheel UPS is an economical device that can bridge the gap between weak sags and temporary voltage loss. This UPS has a high energy storage capacity with a small footprint, and requires no chemical maintenance. This UPS has been successfully applied and demonstrated in Charlotte, North Carolina, by Duke Power. This paper will detail the design, installation, and operation of the UPS that supports an entire industrial process line.

Project Background

In every corner of the United States, there are industrial customers who suffer the damaging and costly effects of electrical sags and momentary interruptions. As the demand for more exacting quality standards draws more sophisticated control apparatus onto the shop floor, industry becomes more vulnerable to power quality (PQ) events. A large degree of success in protection against sags can be obtained using conventional mitigation devices. However, in large industrial processes, there may be a series of linked applications that require full power to maintain production. One of these applications is the common extruder application. A small deviation in electrical supply conditions may create flaws in the extruded product. For years, industry has considered that it is uneconomical to provide continuous power ridethrough for adjustable speed drive equipment in the extruder application. Economics of energy storage were hindered first by the cost of the power electronics, second by the lack of reliability, and third by the environmental impact and space requirements of the chemical storage batteries used to provide the energy for the load. Used to mitigate power quality events, batteries have very short life cycles, as little as one-fifth the warranted life of the battery. Now industry has a new tool that can be employed to add security to the process through the use of kinetic energy stored in a flywheel. Flywheels are not new. What is new is the availability of power electronics to permit the stored energy to be converted to fixed frequency and voltage supply during a discharge event. The combination of modern power electronics and a low speed (<14,000 RPM) flywheel can provide for the multiple short discharge periods required by a power quality event without loss of warranted life or reliability.

Duke Power identified a customer who was losing production through sag and momentary outage events. In fact, the affected customer was out of action for eleven hours following a sag that tripped all four extrusion lines. Remedial action included sending all available employees to the shop floor to work sequentially on each of the four extruder lines. Once one extruder was running the next was worked on. This was a painstaking process because each line produced multiple separate filaments of plastic that had to be threaded by hand through the machine. The candidate process line selected for the energy storage project had 64 such separate filaments.

The cost of a power quality event at the extruder reached far beyond the direct production loss to include the cost of scrap material, the indirect labor cost, and the potential purchase of competitors' material. The plastic strip extruded in this plant was being continuously used as the woven backing of carpet. This particular extruder application had come under careful scrutiny by the manufacturing engineers of the connected customer. PQ mitigating devices such as uninterruptible power supplies (UPSs), ferroresonant transformers, surge arresters and contactor coil-hardening devices had already been fitted, but this only made it more clear that an energy-storage solution was required to enable the process line to ride through sag and momentary outage events successfully.

Energy Storage Systems

Once the extruder process line had been identified as a good candidate for the demonstration of cost effective energy storage, it was important to match available energy storage solutions against the field requirements. Because of the array of different motors and adjustable speed drives involved in the process, it was considered best to support the process with a flywheel storage system that provided an AC output. This facilitated connection to all possible elements of the load. Figure 1 shows the installed flywheel. Earlier solutions had required the combination of a flywheel with DC output to support the drives, and a Written Pole motor generator system to support the remaining motor loads.

Figure 1. Flywheel with AC Output

Total System Solution

Duke Energy and EPRI completed a careful study of the candidate extruder line. The result was the process diagram shown in Figure 2, which illustrates the complexity of the complete extruder system. To keep the plastic strip intact, each of the motor systems shown in the process diagram potentially needed protection from supply sags or interruptions. What was very clear from the study was that the electrical supply to the system was provided from two different utility transformers. This highlighted the need to make some reconnection of the loads to achieve full protection from a single electrical supply backed up with energy storage. What was not known was how much of the process would ride through a sag without the need for energy storage. The answer to this question would require the components of the production line to be tested with a sag generator, a device that is designed to introduce various sag depth and duration characteristics to components of the load. These tests required planning with the connected customer because the process line components were required to be individually tested over the period of one day.

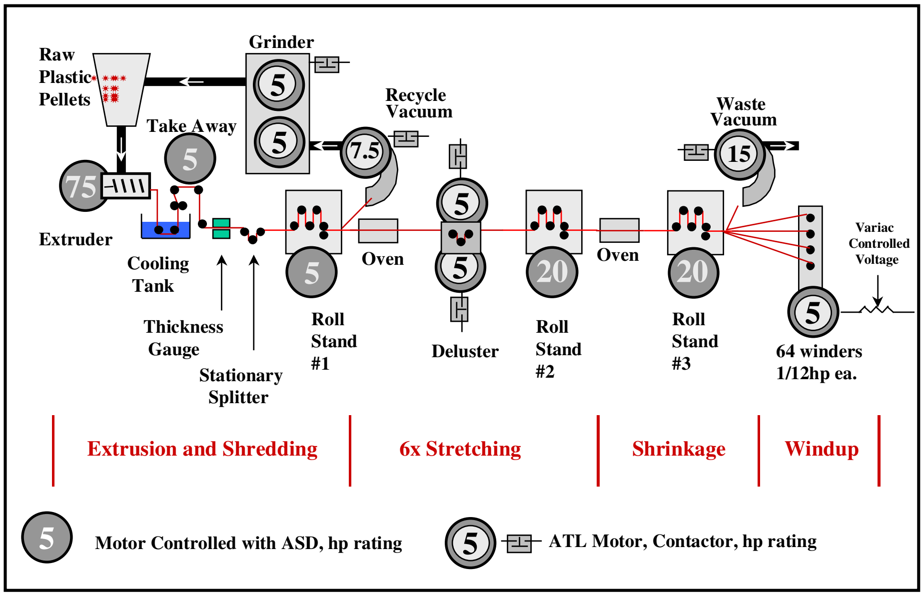


Figure 2. Plastic Extruder Process Diagram

Energy Storage Equipment Selected

Once the load had been fully investigated and the mitigating device selected, the next stage in the process was to make sure that there was complete coordination between the existing system and the new mitigating device. The first stage was to check the configuration of the supply system. In this case, the supply was connected as an ungrounded wye. A neutral was required by the flywheel equipment. This neutral was pulled from the utility transformer to the customer's incoming switchgear. Luckily, for this installation the distances were short. The selected energy equipment had been manufactured and already contained an internal bypass switch and isolators. However, to make sure that the equipment could be safely removed from the process line during normal production, a parallel set of external bypass switches were installed in a floor-mounted cabinet. Figure 3 shows the flywheel (left) and bypass cabinet (right).

Figure 3. Flywheel and Bypass Cabinet

Site Information

In order to document the site conditions fully, monitoring instruments were connected to the drive panel board. These measurements were gathered for a year before the new flywheel system was placed in service. It was noted that if the extruder system stopped due to a sag, approximately 64 bobbins of partially-filled product would be wasted. This material could not be recycled because of the work hardening of the strip during the process.

Sag Testing

Sag testing was scheduled for a plant shutdown during the 1998 Thanksgiving holiday. The results of the testing were very helpful in determining the loads to be supported by the flywheel system. Results confirmed that the connected customer's plant engineer had used PQ mitigating devices to very good effect. Tests confirmed that all rollstands, recycle and waste vacuum motors, takeaway motor, and extruder needed to be on the flywheel output. The 64 winders also needed support, because any change in speed caused the winder to cut the plastic strip and stop operating.

The results of the sag testing were very clear. To achieve ridethrough, all the motors shown on the Process Diagram in Figure 2 needed to be powered from the flywheel system. In order to achieve this result, a new load panel was proposed to handle all extruder loads. This avoided the possibility of maintaining voltage on other unspecified parts of the manufacturing plant which may have introduced new coordination problems.

Official Testing

The manufacturer of the flywheel system arranged for the new system to be tested under the most rigorous of load conditions. A full rated load of a 250 KW, nonlinear 6-pulse rectifier with capacitive filter characteristics was used. Under this onerous load, the voltage distortion was raised to 10%. It was understood that the manufacturer would continue to develop the algorithm that controlled the voltage waveform.

Installation

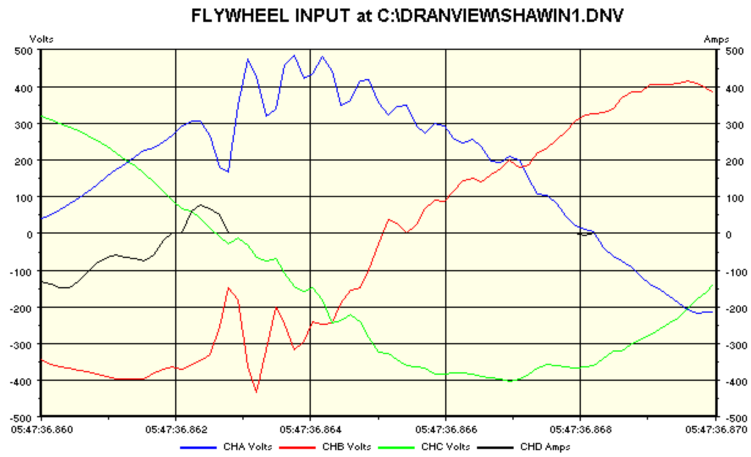
The installation of the flywheel by Duke Power and the storage system supplier was carefully planned and coordinated with the connected customer. As much preparation as possible was made before the plant shut down. All possible conduit runs were made, particularly for the long runs associated with loads that were being reconnected from one power panel to another. The longest part of the installation was the bypass cabling between the new flywheel and the bypass cabinet. For future installation, modifications are required to facilitate the bypass cabinet installation. Once the bypass was in place, each load was carefully connected to the new distribution panel.

Start Up

The flywheel arrived on site with protective support pieces in place of bearings. Once the bearings had been inserted, air from within the flywheel enclosure was drawn out by vacuum pump reducing the pressure in the flywheel enclosure to minimize flywheel system loses. The start up was momentarily delayed by a faulty safety relay, after which the flywheel was run up to its normal storage speed, close to 7700 rpm. Each section of the extruder line was connected to the feeder backed up by the energy storage system. After all the loads were connected, but before plastic extrusion was passed down the line, the incoming breaker for the process was opened. Under these conditions, the process line electrical demand was 80 kVA. The process line ran for up to 40 seconds with the supply breaker open. This test was repeated using multiple short intervals with the breaker open and equally good ridethrough times were obtained. The extruded product was then threaded and the test repeated. The process line demand increased to 85 kVA when raw material was being processed. The process line operated smoothly during the time the input breaker was open. There was no indication that the power supply had been switched off and the high quality extrusion continued without a change. Fine-tuning was completed on the new system, insuring that the flywheel system recognized a healthy power supply voltage soon after it regained specified levels. Monitoring devices were connected to collect input and output voltages and provide information via a modem. The flywheel was also connected to a separate modem to aid data gathering and fault diagnosis.

Performance and Results

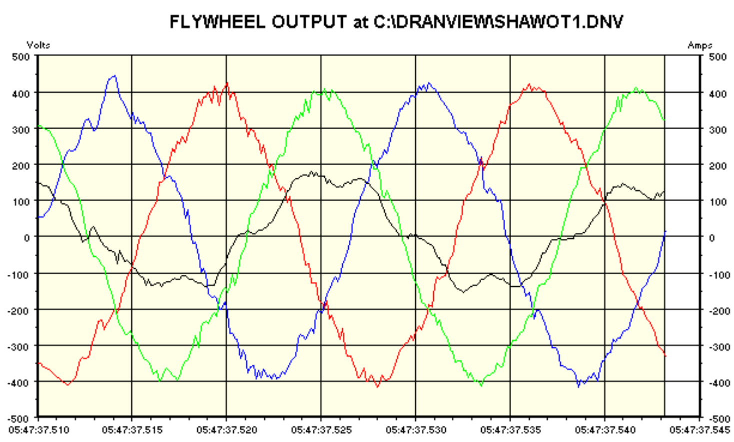
The flywheel demonstrated a very fast response by reacting to the switching event of a power factor correction capacitor located at the local substation. Figures 4a and 4b show the flywheel input and output waveforms, with the black waveform being the load current. When the current waveform “flatlines” in Figure 4a, the flywheel is supporting the load. Within days, the flywheel system caught a 17 cycle sag and protected the extruder process line. Figure 5 shows the input voltage waveforms for the 17 cycle sag that occurred on January 6, 2000. It is worth noting that the three other extruders in the same building were tripped by this sag event causing hours of lost production. It is interesting too, that this duration of sag has been identified in EPRI studies as the most prevalent event on radial feeder systems.



Waveform event at 12/08/99 05:47:36.86

	PrevRMS	MinRMS	MaxRMS	WorstIMP	Phase
AV Volts	272.6	277.5	277.5	0.0	0 deg.
BV Volts	271.7	276.3	276.3	0.0	0 deg.
CV Volts	272.5	277.6	277.6	0.0	0 deg.
DI Amps	105	36	36	0	0 deg.

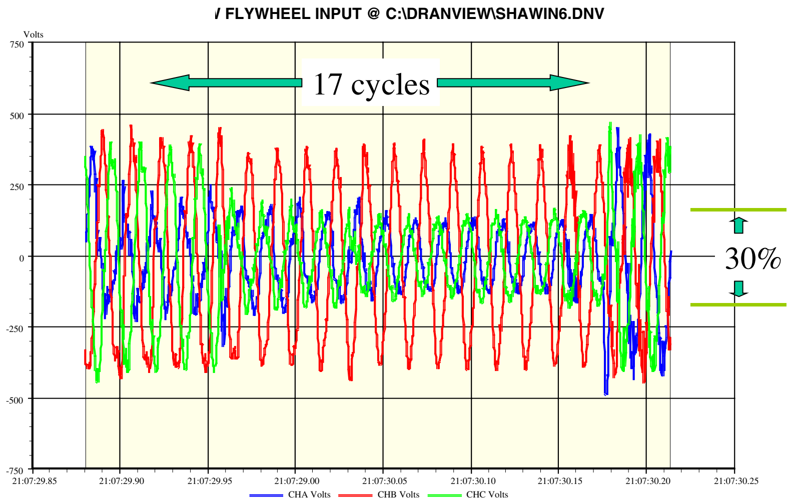
Figure 4a. Capacitor Switching Response (Flywheel Input)



Waveform event at 12/08/99 05:47:37.51

	PrevRMS	MinRMS	MaxRMS	WorstIMP	Phase
AV Volts	273.1	267.9	276.4	0.0	0 deg.
BV Volts	272.2	271.8	276.4	0.0	0 deg.
CV Volts	273.3	270.1	273.8	0.0	0 deg.
DI Amps	97	104	110	0	0 deg.

Figure 4b. Capacitor Switching Response (Flywheel Output)



Waveform event at 01/06/00 21:07:29.88

	PrevRMS	MinRMS	MaxRMS	WorstIMP	Phase
AV Volts	278.3	86.7	262.8	0.0	0 deg.
BV Volts	277.1	251.5	297.2	0.0	0 deg.
CV Volts	278.1	84.4	278.5	0.0	0 deg.
DI Amps	110	9	59	0	0 deg.

Figure 5. The First Save Event --January 6, 2000

This installation at present only uses about one third of the flywheel's rated capacity and so measurements of efficiency give lower than the nameplate information. This will change as the load is increased by the connection of another extruder line.

Economics

Based on the electrical monitoring and 1999 plant maintenance records, the Extruder Line #1 was stopped on average 30 times per year due to power quality events. The line was down on average 45 hours. This downtime represents $15,000 dollars of lost product that can be saved with a new energy storage device. Each time an outage occurs, the restart time is 1.5 hours and absorbs the labor of at least two operators. At the time of system trip, all the material on partially filled bobbins (<1/2 full) is scrapped. This represents on average two hours of production, as a full roll takes four hours to produce. With the process line out of action, potentially the company has to purchase material from a competitor to insure that production is maintained in the carpet backing weaving plant.

Plans are in place to improve the efficiency of Extruder Line #2 so it can be added to the flywheel. When this additional line is added, the savings will increase $36,000 dollars, for a total of $51,000 annually.

Conclusions

The flywheel with AC output has been applied to a critical load and has performed well, protecting the load from sag and momentary power outages. Close to 40 seconds of ridethrough is currently available to the extruder line. Part of this energy will be used on other extruder lines to give the customer increased value for money. Work needs to continue on the harmonic content of the load voltage waveform. It is very clear from the results of this demonstration project that there are many industrial applications that would gain from this form of low-speed flywheel energy storage system with AC output.