Analysis Of New Energy Storage Technologies For Power Quality Solutions In The Distribution Network.

Ricardo López, José P. Rasgado and Héctor G. Sarmiento,[1] Instituto de Investigaciones Eléctricas, MEXICO

Abstract

In this work, a study is developed by IIE (Instituto de Investigaciones Eléctricas, México) due to the necessity of finding new Power Quality solutions for the distribution networks. Different energy storage technologies have been studied such as *Flywheels* (FW), *Superconductors, Supercapacitors, Fuel Cells and Advanced Batteries* for short-time applications (0 – 20 s) as well as their market projection in the short term. Likewise, new capacities for power electronics devices and their evolution have been reviewed, compared and analyzed for a direct application on distribution networks. Recently, a survey questionnaire has been sent to different industrial customers, in order to obtain direct information from them and evaluate the possible applications of these emergent technologies.

INTRODUCTION

Technological advances at the present time have waken up several energy storage technologies, developments that began several decades ago like: Flywheels or superconductors, a concept already a century old, that today reappears, motivated by the necessity to find practical and economically feasible solutions. Among the many applications of energy storage systems, the applications of short-time duration for distribution networks with industrial users with critical loads, is a sufficiently justified possibility.

Private international and governmental groups of research, such as EPRI, DOE, SANDIA [1], in addition to many manufacturers and universities, dedicate great amounts of resources to the development and improvement of energy storage devices. In parallel, the development of power electronics is subject to a continuous evolution. Nowadays, it is possible to use jointly the commercially mature Insulated Gate Bipolar Transistor (IGBT) and the recently developed Integrated Gate Commutated Thyristor (IGCT) to combine the potential of both technologies, opening the possibility of direct application of multilevel converters in 13.8 or 23kV without the interface transformer [2-3].

IIE facilities are located in Cuernavaca, Morelos, Mexico, which are exposed constantly to power disturbances all the year. Some simulations have already been done by means of a simple energy storage conceptual model, considering the published data from manufacturers of Low-speed Flywheels (FW) as well as Nickel Cadmium and Lead Acid Batteries, in order to evaluate their behavior and internal application feasibilities. With this, we propose, an integral alternative for mitigation of the frequent problems of micro-interruptions and voltage sags and the consequent loss of information due to PC's mal function.

In Mexico, more than 65 % of the electrical energy is supplied to industrial customers by means of 115/85/34,5/23/13,8/4,16 kV and lower voltages. The common disturbances on the distribution network are due to instantaneous voltage sags and micro-interruptions (less than 3 seconds) [4]. However, only a few companies have installed power quality monitoring equipment, therefore it is very difficult to determine systematically, the magnitude, duration and frequency of a sudden disturbance on the network, as well as the economic losses incurred. Due to this, IIE has initiated contact with several companies and the main utility in Mexico *Comisión Federal de Electricidad* (CFE) and *Luz y Fuerza* (LyF) to encourage the installation of an energy storage system at the most suitable place and to evaluate results jointly.

[1] hsu@iie.org.mx

Internal monitoring and conceptual solutions

Monitoring in different substations at IIE began in July 2003, to register the parameters of energy provided by the electrical utility (LyF). Measurements began in substation #2 of IIE, which feeds three buildings (26, 27 and 29) among several others. For this, a network-analyzer is being used. The load of the 3 buildings consists mainly of personal computers and lighting systems, which do not exceed 100 kVA. The substation receives a 23 kV feeder through a 500 kVA transformer, 23kV/220V Δ-y. The feeder length is 12 km approximately and crosses the City of Cuernavaca. This zone presents a greater flashover activity during the rainy season. Table 1 shows the number of events that appeared in an interval of two months.

Table 1

Characteristics of Interruptions on site period (07-21-03 to 09-16-03)						
Classification by duration						Total
Time	< 1 min	1 < 5 min	5 < 10 min	10 < 20 min	> 20 min.	576min 12sec
Number of interruptions	7	17	7	8	5	44

The accumulated time in the total number of interruptions surpasses 9 hours in a monitoring period of 51 days. It is necessary to clarify that although these months correspond to the rainy season and electrical storms, the majority of the interruptions happened when no storm was present. Table 2 shows momentary voltage sags registered during that same time period. The number of voltage sags registered was of 291and the voltage dip average was of 0,74 pu. The average duration of these events was of 212ms.

Table 2

Voltage Sags registered during 51 days (127 V basis)				
Total number of events	Voltage average		Maximum voltage sags registered in pu	Average duration time
291	94.048 V	0.74 pu	0.34	212.888 ms

It is important to mention that the number of computers in the IIE is about 1600. Approximately 56 % of these computers are concentrated in those three buildings. Approximately 30 % of the equipment is equipped with a UPS with 700 VA capacity. The UPS is for a 5 minute duration of total load and 10 minutes at medium load and the recharge-time is approximately of 3 hours. Generally it is recommended to switch-off the PC's if the interruption is longer than 3 minutes, in order to avoid battery discharge, otherwise the battery would not be ready for a subsequent event.

In order to consider some effects in personnel productivity, the payroll at IIE is approximately $6.000 USD/hr. Considering the sum of time (576 min) of interruptions in table 1 and that only 50% of the personnel is affected, the economic losses by productivity is around $29.000 USD for 576 min.

SIMULATIONS OF A SIMPLE ENERGY STORAGE CONCEPTUAL MODEL

Considering that the great amount of disturbances appearing in the distribution networks are voltage sags and that these can cause a wrong operation or disconnection of an electronic load, like a PC, the possibility of installing UPS's is being considered to give support in some buildings of the IIE instead of one UPS at each computer equipment. This initiative must be justified technically and economically, reason why some simple models have been developed and some simulations have been done. The simulations represent the same scenarios with three possibilities of different technologies: Conceptual Flywheel, Lead-acid and Nickel-Cadmium batteries energy storage systems. The model has been implemented with MatLab-Simulink software.

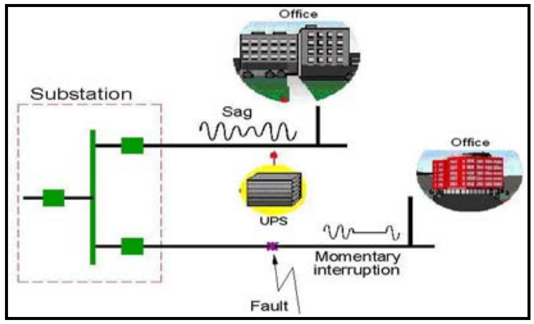
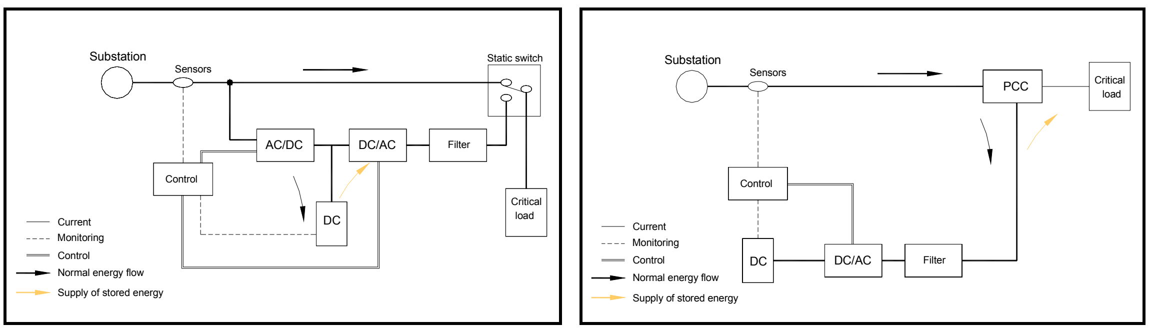


Fig. 1 Schematic diagram of IIE facilities and the possible location of the UPS.

The single-wire diagram used for the simulation is illustrated in figure 1 for a load system of 100 kW, 120 kVA, 127 Vac. The representation of the disturbance is made by means of an instantaneous fault of a few cycles to cause a voltage sag in the supply of one of IIE's buildings.

In the conceptual single-phase simulation of a Flywheel system, an interactive type topology was considered and the semiconductor used in the power electronics is IGBT. In the case of the batteries an off-line topology is being considered. Figure 2 shows the block diagrams of the topologies Off-line (a), and Off-line interactive (b).

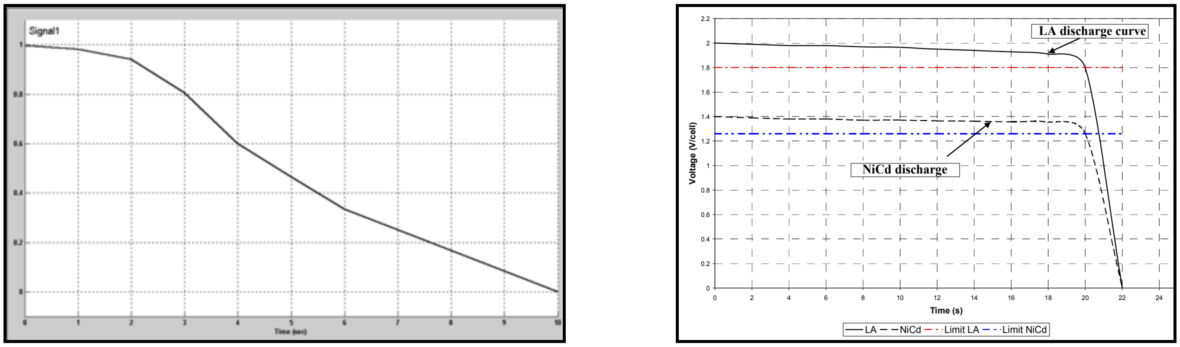


a) b)

Fig. 2 Topologies used in the model Off-line (a) and Interactive (b).

In the conceptual operation of the Off-line system when an anomaly on the network appears, the static switch transfers 100% of the load to the inverter, isolating the load from the network. The total transfer time after the switch command is usually less than a half cycle. The major problem associated with off-line technology is the total time required to measure-decide-and transfer operation. However, Line-interactive topology utilizes the bi-directional inverter to perform two functions, namely to run the load and charge the battery. As the name implies, the inverter interacts with the utility to maintain rated output voltage to the load. An ability to interact with the utility supply improves the overall energy storage system performance over the off-line systems. Line-interactive system represents a very good level of response for a moderate investment and is one of the most used short-duration energy storage systems for distribution levels.

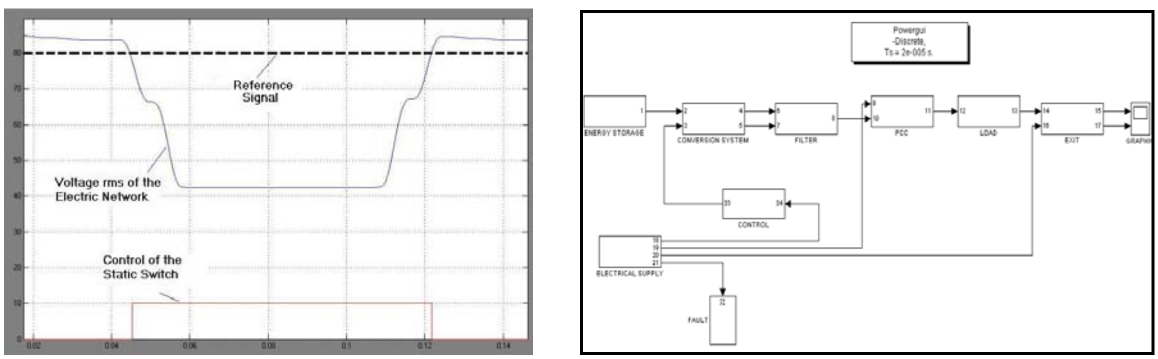
The behavior of the discharge of the energy storage device was obtained from published data of the manufacturers of low-speed Flywheel [6], as well as the LA and NiCd batteries [7-8]. In the computer simulations, the discharge characteristic of the storage equipment has been represented by a function named "signal building", function that is represented in a simple way within Simulink software, both for Flywheel and the batteries. The discharge characteristic of the FW corresponds to a capacity up to 200 kVA with a duration up to 10s, whereas the characteristics of unloading of the bank of batteries are considered for a capacity of 120 kVA and duration up to 20s. Figure 3 shows these discharge curves which were taken from specifications published by the manufacturers of these technologies.



a) b)

Fig. 3 Discharge characteristic of (7700 rpm) low speed FW (a) and Ni-Cd / Pb batteries (b).

Figure 4 represents the basic operating signals of the control system used in the simulations, where the reference signal is shown, the detection of voltage sag and operating signal of the transfer static-switch for the case of the system with off-line topology corresponds to figure 2a. The control system compares the voltage of the network in the load connection node and a reference signal. This comparison is turned to pu values and the result will be the modulation signal of the PWM control of the inverter.



a) b)

Fig. 4 a) Controls signals reference signal of Off-line topology. b) Simulink Block diagram of Interactive topology.

The control in the interactive scheme line does not require a transfer-static-switch, for this reason the response of this scheme is faster than a conventional off-line scheme. The voltage of the inverter is injected at the network-load "T" point by means of a series connected transformer, and the operation of the control system is:

$$Spwm = \frac{Vref - Vpc}{Vref + (Vref * 0.01)} \tag{1}$$

where,
Vpc- Voltage at the point of load
Vref- Reference voltage signal
Spwm- Input signal for PWM control.

$$m = \frac{Spwm_{\max}}{Port_{\max}} \tag{2}$$

where,
m- Relation of modulation
$Port_{\max}$ - Maximum value of carrier wave
$Spwm_{\max}$ - Maximum value of modulation signal (sinusoidal wave)

$$Voi = m * Vin \tag{3}$$

Voi.- Output voltage of the inverter
Vin.- Input voltage of the inverter

thus, the voltage injected by the inverter to the network will be proportional to the *Error*, which is:

$$Error = Vref - Vpc \quad (4)$$

From equation 3,

$$Voi = \frac{\left(\frac{Error}{Vref + (Vref * 0.01)}\right)_{max}}{Port_{max}} * Vin \quad (5)$$

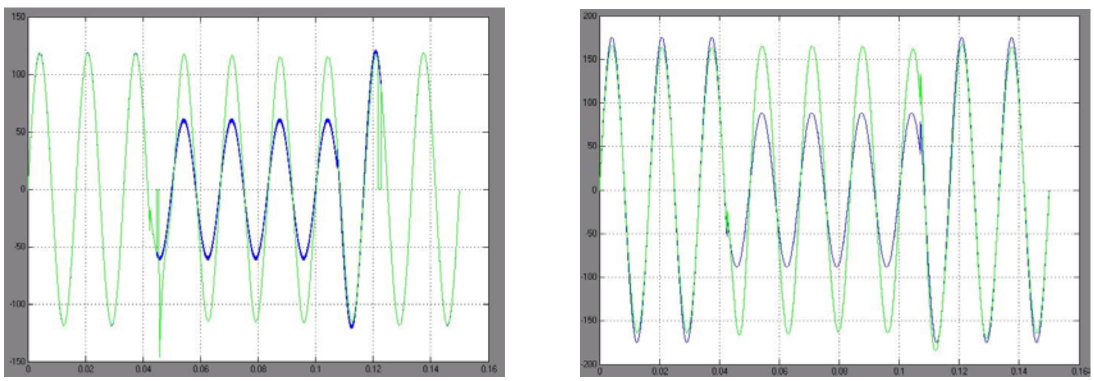
simplifying the equation, then:

$$K = Port_{max} * (Vref + (Vref * 0.01)) \quad (6)$$

Finally, replacing (6) in (3),

$$Voi = Error * \frac{Vin}{K} \quad (7)$$

Equation 7 represents the amount of voltage that will be injected to compensate the voltage dip caused by a fault in the parallel circuit of figure 1. Figure 5a shows the output simulations for the bank of batteries of NiCd and LA. Figure 5b shows the output simulation from conceptual Flywheel model with an interactive topology.



a) b)

Fig. 5 Response to a voltage sag simulation at 0.6 pu and 56 ms, a) Off-line topology for battery banks NiCd or LA, b) Interactive topology for a Flywheel low-speed characteristic.

It is possible to observe in figure 5, the difference between the response time of the two topologies for the same fault case. With a mature technology like IGBT, it is possible to use flywheels or battery banks and obtain a similar response for the On-line topology. Nevertheless, the difference in costs is considerable and taking into account that the cost of the power electronics is 40 % of the total cost, the interactive topology has a greater service life in the power electronics. On the other hand, for distribution levels, the new generation of converters with IGCT technology are already commercially available.

The quotation of the equipment UPS with NiCd technology for each one of the three buildings is about $70,000 USD for 150/120 (kVA/kW) 8 min. capacity, and for a single UPS for the three buildings is $183,000 USD for 400/320 (kVA/kW) to 6 min. capacity. Whereas a system FW has a cost of $100,000 USD for a 250 kW for a support time of 12,5s to total load and 150 kW, 20s approximately.

SURVEY QUESTIONNAIRE

A survey questionnaire is being carried out with industrial customers which were selected by their critical loads and sensible line production. In the survey ten questions about the type of critical load were formulated altogether, effects related to the disturbances, knowledge of the possible solutions, and if the industrial customer would agree in participating in a demonstration project of these new energy storage technologies for the solution of PQ problems.

The most interesting information that has been received until now corresponds to a textile plant which reported disturbance events in the last three years. This plant has PQ monitoring equipment installed and keeps good communication with the power utility. This plant has also different auxiliary systems which are controlled by numerical control equipment, including other subsystems as compressors, nitrogen blowers, water pumps, speed drivers, etc. Twenty voltage sags were registered in the years 2001 and 2002 and the sum of economical losses of these two years was $756,373 USD.

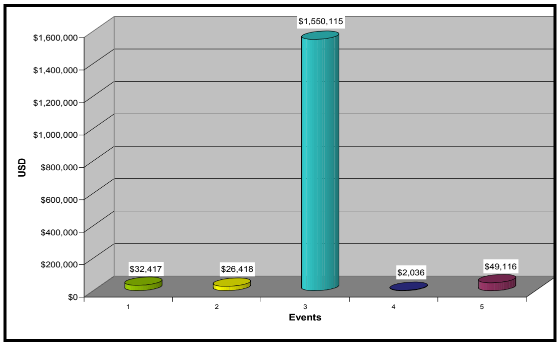


Fig. 6 Event registers during 2003 in a textile plant in Mexico.

Table 3 Successive voltage sags in a textile plant.

Recording-time	Magnitude pu	Duration	
11:19	0.57	760 ms	45.6 cy
11.20	0.83	376 ms	22.56 cy
11:24	0.63	667 ms	40.02 cy

During the first semester of the year 2003 five events were recorded by the textile company. One of them was due to an explosion of a utility´s capacitor bank at a remote substation which caused three successive voltage sags. The remaining events were recorded by different causes and different dates during the year. Figure 6, shows the economical losses reported by the textile plant, where the event number 3 includes the huge economical losses (more than 1'500,000 USD) caused by the three successive events (counted as an event) as described above and the other four single disturbances occurred during the same year reporting less economical losses. Table 3 shows the magnitude and duration of each successive voltage sag event. Each successive voltage sags was separated by one minute time, causing an eventual disconnection and loss of configuration of the line production as well as the auxiliary or adjacent subsystems in a chain reaction until several production lines collapsed. Some users demand more attention of the supply company to find solutions and one of them would be the short-time energy storage systems.

Application Scenarios

Nowadays it is possible to have electrical networks with exceptional reliability indices, superior to 99% having redundant or exclusive supply. Nevertheless, this does not guarantee that disturbances in the voltage waveform cannot exist, since most of these disturbances are very fast and, for many users, are not detectable, except, for extremely sensible processes, such as semiconductors, paper, textile, automotive, sterilized processes, pharmaceutics, food processors, glass, petrochemical processes, etc.

The large and varied geography of Mexico, allows to have several "industrial parks" distributed throughout the country, that integrate diverse types of companies such as already mentioned. The continuous development of these emergent technologies can give joint solutions to a group of companies, instead of individual solutions, so costs could be shared. Therefore, Mexico is a country that requires effective technical solutions to solve the PQ problems in distribution networks.

Conclusions

The case presented by the textile company is an example of how successive events affect in a significant way sensible processes causing enormous economic losses. The disturbances registered in the facilities of the IIE, reflect a small part of the real problem that exists in the distribution networks in Mexico and how much can be done. The monitoring will continue for the next two years, in order to collect data to be compared during the different seasons.

In Mexico, there are no statistics for the most frequent short-duration disturbances in the distribution network. On the other hand, the number of industrial users which have PQ monitoring equipment in their facilities are a few. This means that the great majority of industrial users do not have any historical statistical data of the disturbances that may cause production breakdowns. On the other hand, the power utility does not measure and register any of these disturbances. There are complaints by the users due to the lack of solutions and communication to resolve the problem.

The IIE is proposing to the utilities (CFE and LyF), to make a statistical study that allows identification of the indices of PQ which prevail in selected areas of the distribution network. Afterwards, to conduct a feasibility study of different technological options, such as the short-time energy storage systems to benefit groups of users instead of individual ones.

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