New FACTS Equipment in an Enhanced Version of Smart Grids

The Magnetic Gate

Julio Enrique Posada C.
EIII Transmission & Distribution of Energy
San Salvador, El Salvador, C.A.

ABSTRACT

This work is a qualitative proposal of a new FACTS device, which aims to repower the "Smart Grids", to a higher level. The existing FACTS that are covering the role of power flow control have the disadvantages of the use of electronic devices, and generate excessive heat and harmonics injected into the network. These devices are expensive and their regulation is binary: zero flow or total flow. This proposal offers a more versatile power flow control from zero to one hundred percent of its nominal capacity. Smart grids will no longer need to have a Relay Counseling Center, and the communication by pilot wire or other means available will be enough to control and protect the network. Therefore, due to fewer crossed and analyzed data, the laborious task of considering whether an event is really a failure, will be less complicated and will be carried out more quickly.

In combination with phase measurement units (PMUs) for each MAG, approximation techniques will not be necessary to estimate the variations caused by the dynamics of the demand, because the MAG is operating in "floating mode" as discussed further below. The network automatically and gradually rearranges these variations. Incomplete observation could be used for measuring voltage and current signals of the network in some specific points in the network.

Keywords: Meter Reading, Power Generation, Dispatch, Power Demand, Power System Protection.

1. NOMENCLATURE

FACTS: Flexible Alternating Current Transmission System.
MFC: Magnetic Field Control.
CT: Current Transformer.
CVT: Capacitor Voltage Transformer.
CPU: Control Processor unit.
CB: Circuit Breaker

2. DESCRIPTION OF EQUIPMENT

The MAG is a controller bidirectional power flow device, proposed to: regulate the power flow at a given point of a transmission system, eliminate instability events, protect the system against failures short-circuit on transmission lines and correct the power factor on a particular node where the existing capacitor's group has failed (or where greater accuracy is necessary for the correction already made). Its operation has a greater versatility that the mechanisms currently used and it will be very useful when for some reason we want to have control of the load flow retaining it (in whole or in part) at any point, in order to divert the flow of power at our convenience elsewhere in the system.

The protection of existing power systems for the transmission lines (main and backup) currently held by relays of: distance, differential, earth fault, overload, etc. will become part of the backup protection, moving completely to MAG the main protection function. Moreover, the protection of substations in the inside (transformers, capacitor banks, buses, etc.) can be added in this new system or remain protected by the current schema.

The author presents his work at the qualitative level but shows some calculations assuming the MAG works as a reverse of a current transformer.

MAG is a series of coils (coils 2) feeding a magnetic field within a flexible armor used as a second coil (coil 1) by circulating the field around the high voltage current, that the current induced by the field is opposed or in favor to the line current (primary current) decreasing or increasing it. The author has called this arrangement of coils 1 and 2 as "Magnetic Cannon (MAC)" which is the main part of the MAG. (Figure 1)

The coils 2 of MAC supply sufficient power to control the magnetic field on the primary line. This means that by varying the injection current to the coils 2, is possible to control the primary current.

The MAC can be operated in automatic mode by the MFC, which is basically formed by a power supply, a commutator to assign the required amount of current to be injected to the coils 2 and a CPU which analyzes and decides the actions to make. (Figures 2, 3 and 4)

The CPU may need help of PMUs in the network to monitor and process the parameters of the corresponding node. Each MFC receives signals from the associated measuring equipment (current and potential transformers) as well as information from the surrounding MFC.

When a load current flows from one node to another through a transmission line, such current leaves the first node and then enters the second node. In the event of line failure, events happen otherwise, the current will be from both nodes to any intermediate point of the line to feed such failure.

Determining the point of failure may be performed as follows: Simulations of three phases to ground faults at the midpoint of the "n" lines of the system should be made (Simulations for each type of failure should be performed); the percentage of

short circuit current contribution of the two nodes that feed the fault must be tabulated for each line for each type of fault.

The percentage of the power contributions will be the same to the contributions of the coils 2 of each MAC, in each of the two adjacent nodes when a real fault occurs at the midpoint of the line. Variations of this percentage represent the separation from the midpoint when a real fault occurs. There are other ways to calculate the point of failure, always through the percentage of current drawn by the coils 2.

Because the strangulation in the two MAGs of the circuit breakers that feed the failure will not allow the TCs to rise inside its magnetization curve, the protective relay cannot execute their function. The MAGs of both points will determine the fault, interrogating each other about the direction of current flow. Having detected the fault, each MAG will send a signal trip to their respective relays or directly to the trip coil to isolate the failed line from the system.

Simplifications

Basically, the MAG acts as the inverse of a current transformer (CT^{-1}) where, for simplicity the use of the equivalent circuit is omitted, it has been assumed zero leakage flux and the value of the impedance of the primary assumes the same value as its resistance.

Another approach to be taken into account is that the number of turns of the Coil 1 equals the number of primary turns N1 as in the case of a transformer. This is because the primary conductor has no loop around the armature, but the armature has a winding around the primary conductor.

Finally, it is assumed that the current and line voltage are exactly in phase with the secondary signals of the current and voltage transformers respectively. Since it is likely that this requirement is not met, appropriate adjustments shall be made by some means or with the assistance of the PMU mentioned above.

3. MAG OPERATION

The Magnetic Gate can be operated in manual and automatic mode. We must first set the parameters to be monitored by the MFC, in their intensity. This may be done by: choosing the level 1 for slight variations caused by natural changes in demand. The Level 2 for medium changes due to events of instability. Finally, level 3 for the abrupt changes caused by failure of any transmission line of the system.

Manual Operation Mode

Manual mode, in turn, can be used in fixed mode and power factor correction mode.

Fixed Mode Operation

The Load Dispatch Centre fixes the MAG at a predetermined maximum value of flow of primary current in a circuit breaker system, which can reduce the flow in any case. This is a way to modify the distribution of natural load flow and force the system to behave in our best interest.

Power Factor Correction Mode

In manual mode, the "Load Dispatch Centre" can also correct the power factor on a particular node in the network. For these we need to perform the two following steps in all lines and, in all the breakers of each line that feed the node where the power factor will be improved. Step one through the MAG, we slide the angle of the current flow between the signals in the coils 2 and the secondary current of the CTs. Step two is to make a current injection (by means a voltage elevation) at the node in question, from the adjacent nodes. This current will be consumed by the reactive impedance of the load and the process is equivalent to an artificial modification of the "Ohm's Law" in phase form. (Figures 5, 6, 7, 8, 9, 10 and 13)

The current injection procedure to correct the power factor applies only for emergencies. This is for example, when a capacitor's group has failed. This requires at least two generation nodes on each side (west and east or north and south) of the node to correct PF increase the voltage. Thereby, the neighboring lines of that node, inject (the load takes more current due a voltage elevation and the slide of the angle of the current) current through the MAG of each Circuit Breaker involved according to Figure 5.

This injection of current is achieved by manipulating the magnetic fields in the MAC coils, over each of the two ends of each transmission line connecting to the node where it is desired to correct the power factor. Manipulation should generate a magnetic field in the same direction of the field generated by the line current when the current is injected into node where it is desired to correct the power factor. Otherwise, the manipulation should generate a magnetic field in the opposite direction of the field generated by the line current when the current is injected from the node where it is desired to correct the power factor.

Automatic Operation Mode

The automatic mode is used in three versions: floating, instability detection and line protection.

Floating Mode

The MAG measures level 1 variation caused by a natural dynamic load flow in a transmission system and allows the strangulation to rearrange slowly.

Instability Detection Mode

Under this mode, the MAGs measures the variation in level 2, and it freezes in fixed mode all points with that level, eliminating the oscillations of the power flow that occurs during these events. At the same time determining the point of greatest instability and causes (if it's necessary) the trip of corresponding CB linked to that point.

Line Protection Mode

All MAGs near the point of failure detect variations in level 3 and immediately freezes the flow of current in a maximum (nominal) value. The two MAGs associated with circuit breakers that feed fails, send the signal to trip the corresponding relays or directly to the trip coil, to separate the failed line from the system. The new way to identify the line that has failed will be according to the direction of current contributions from the two nodes involved in the fault location. (Figure 11)

4. BASIC CALCULATIONS (example)

Known Variables. Available values are for a line that transmits 100 MW at 115 kV in three phases:

- Primary current I_1 (500 amperes)
- Primary wire resistance R_1 (0.1 Ω/km)
- Primary turns N_1 (100)
- Secondary turns N_2 (10,000)

Unknown Variables. The variables to be calculated are:

- Primary voltage V_1
- Secondary current I_2
- Secondary voltage V_2

Formulae Used:

- $N_1 I_1 = N_2 I_2$ (1)
- $V_1 = I_1 R_1$ (2)
- $V_1 I_1 = V_2 I_2$ (3)

Values obtained in normal condition:

- $V_1 =$ 0.05 volts/meter
- $I_2 =$ 5.0 amperes
- $V_2 =$ 5.0 volts

Values obtained in short-circuit condition for 40 kilo-amperes:

- $V_1 =$ 4.0 volts/meter
- $I_2 =$ 400 amperes
- $V_2 =$ 400 volts

The estimated data is reasonably acceptable.

5. ALTERNATIVE FOR THE MAGNETIC CANNON.

We can replace the Magnetic Cannon using a set of coils with the winding concentric donut-shaped, but that are different from the toroid arrangement. The magnetic field generated in the armature in the center of the donut (where the primary current circulates transversally) induces a reverse or in favor flow to the primary current, decreasing or increasing totally or partially. (Figure 12)

6. CONCLUSIONS

In this case we wish to control an electric power in the range of 100 megawatts or more, by means of a magnetic gate of a few watts. If we see the example of a hydroelectric dam with a reservoir of 10 square kilometers and a 50 meter hydraulic head over the discharge pipe. Then, we have that the energy required to close a valve in the pipe is exactly the same as the one required to close the valve in the case that the reservoir is 100 kilometer square (10 times higher of stored energy). The same applies to the current flowing in the primary transmission line, since the energy is channeled in this case by an electrical conductor, and therefore it is particularly "quantized" making it easily controllable.

In both cases the energy necessary to close a mechanical valve and the energy required to operate a magnetic valve, is small compared to the energy they are handling.

7. PHILOSOPHICAL METHOD USED FOR THE DEVELOPMENT OF THIS WORK: "VECTOR-GUIDE IN PROCESSES FOR SOLUTIONS NON EXISTING (GPS VECTOR)"

This philosophy is based on a presentation prepared by the author (Julio E. Posada) developed and exposed in 2004 in his country, El Salvador during the Eleventh National Congress of Engineering, CONIMEIRA XI; according to the document "CONVERSION OF SUPERIOR EDUCATION, FOR AN ACCELERATED DEVELOPMENT OF TECHNOLOGY".

The document mentioned above, basically states the following precepts:

- All Great Discoveries are based on Basic Concepts of Science. If a discovery is made with advanced technology and high-level knowledge, then it is not a discovery but is an extension of a previous discovery.
- Developing a GPS VECTOR based on basic existing concepts of science, serves as a platform for development teams to implement it and produce a mechanism that at this moment DOES NOT EXIST, but will contribute to the evolution of mankind.
- All Intellectuals have the ability to make great discoveries in any field of science, as long as they are provided with the basic knowledge related to that discovery.
- The basic knowledge can be transferred without much effort from one individual to another, through daily contact between them. This phenomenon is called by the author as *Contamination of Knowledge*. Corporations should allow their scientists in the various fields of science to contaminate information to colleagues or fellow workers, who have the same or different specialties. This will help to promote the acquisition of basic knowledge of a specific topic, on individuals working within the factories or labs.
- To give further impetus to the concept of *Contamination of Knowledge*, corporations must build libraries compendia of basic concepts with minimal use of equations and numerology. This way all of their employees may acquire concepts related to a mechanism that they are currently working on or, to find conceptual support for successfully carrying out their mission. These libraries of compendia of basic concepts may be structured on a corporate level in the first instance, but could be extended to local or federal government, in order to promote the nationwide (or worldwide) development of technology more quickly.

The "Vector GPS" concept shows a futuristic event, and offers the appropriate and necessary technology to carry out the mentioned event. On the other hand, “Science Fiction” shows a futuristic event, but does not offer the technology that really allows us to make the event happen.

8. REFERENCES

[1] Stanley H. Horowitz, Arum G. Phadke y Bruce A. Renz, “The Future of Power Transmission” IEEE Magazine, Taking Measure of the Smart Grid around the World, March-April 2010.

[2] Enrique Santacana, Gary Rackliffe, Le Tang and Xiaoming Feng, “Getting Smart” IEEE Magazine, Taking Measure of the Smart Grid around the World, March-April 2010.

[3] C. Russell Mason, “The Art and Science of Protection Relays” Mexico: C.E.C.S.A. 1980, pp. 131-138.

[4] Vembu Gourishankar, “Electromechanical Energy Conversion” Mexico: R.S.I. 1969, pp. 36-40.

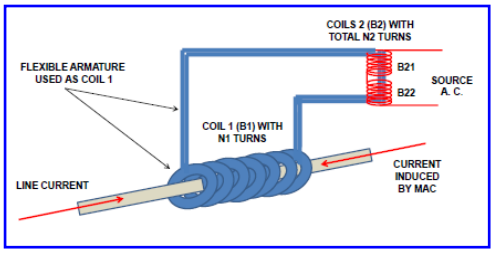

Figure 1. Magnetic Cannon

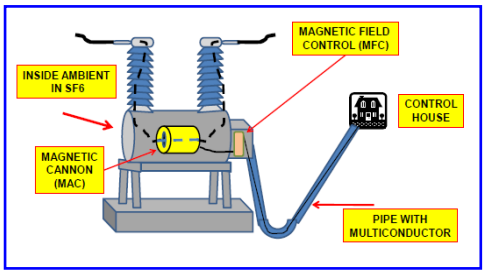

Figure 2. Overview of Magnetic Gate and Parts

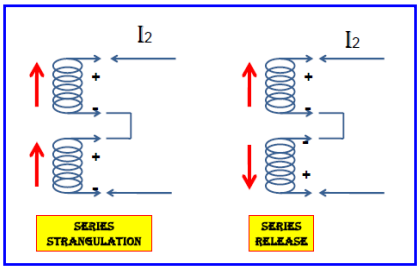

Figure 3.Interconnection of Coils

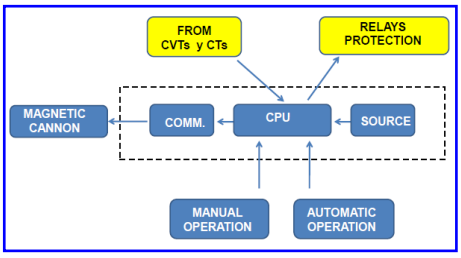

Figure 4. Interconnection Diagram of Parts of the MAG

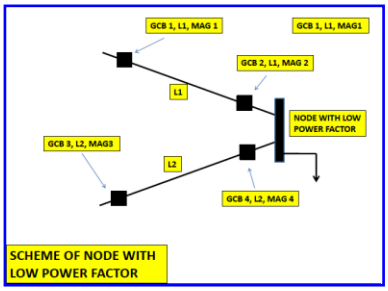

Figure 5.Scheme of a node with low power factor

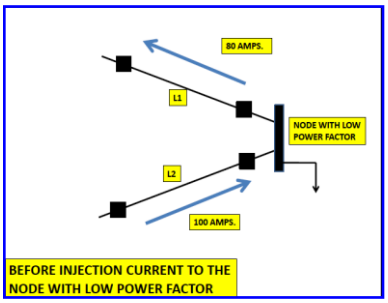

Figure 6. Before injecting current to the node with low power factor

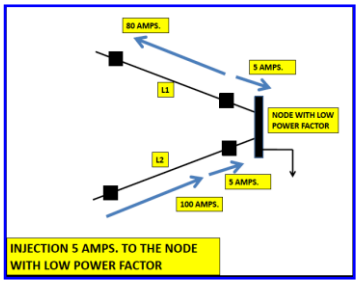

Figure 7. Injecting 5 amps. To the node with low power factor

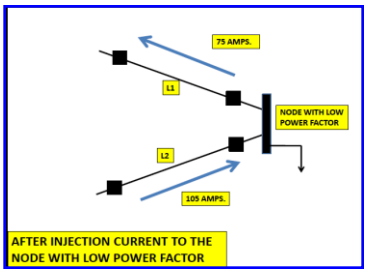

Figure 8. After injecting current to the node with low power factor

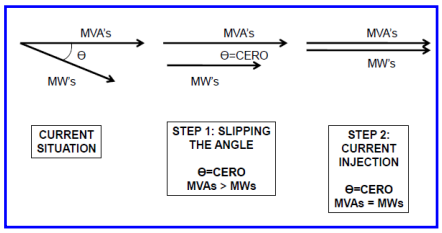

Figure 9. Steps to follow in all lines and in all the breakers of each line that feed the node where the power factor will be improved

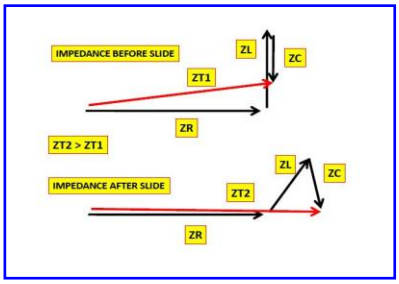

Figure 10. Artificial Equivalent Modification of the Ohms Law

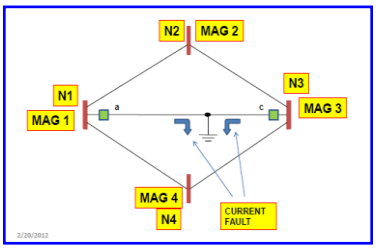

Figure 11. A current flowing toward the center (between the two circuit breakers) line from two adjacent nodes, it indicates failure

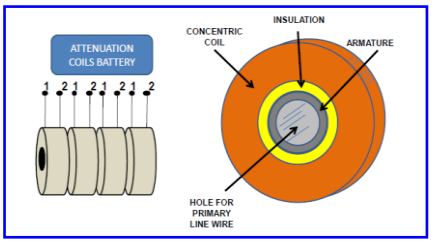

Figure 12. Alternative for Magnetic Cannon

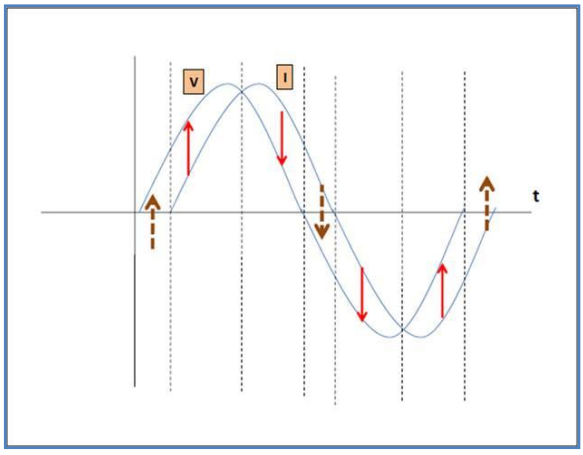

Figure 13. The current curve is placed in phase with the voltage curve by the slip angle caused by the MAG in order to correct the power factor