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Analysis and Simulation of an Uninterruptible Power Supply System–UPS from the Electric Power Quality Viewpoint

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Abstract-This paper describes and compares different rectification technologies applied to uninterruptible power supply systems UPS, and determines –using simulations - which of the systems performs best from the power quality viewpoint.

Key words: IGBT, Orcad, Power Electronics, Power Quality, Pspice, PWM, UPS, Rectifier.

I. INTRODUCTION

Uninterruptible Power supply (UPS) are non-linear loads, which rectifier creates an incoming high line current harmonic distortion inside the supply system and the industrial customer, not only from the technical viewpoint (increasing power consumption, risk of damage and loss of sensitive equipment) since the additional financial resources in maintenance and additional equipment to support the load conditions.

From the power quality viewpoint it is interesting to evaluate the influence of different rectifier types at device input level, as well as the harmonic load, the power factor and the utilization factor for each of the system devices.

The main purpose of this paper is to present the results of the analysis of the harmonics problems under a stable condition for low-voltage systems. The analysis is based upon the simulation of UPS elements that generate harmonics to the system. We intend to find a more feasible technology from the technical viewpoint, for both the users and the system suppliers, avoiding the distortion produced by the rectification device on the network.

II. UNINTERRUPTIBLE POWER SUPPLY SYSTEMS (UPS).

The main purpose of an UPS is to permanently provide outstanding quality output power flow, ensuring the protection of the loads connected to the inverter. However, the device should also perform as a load not to damage the power supply from the main feed. The ordinary rectification process in these devices behaves as a supply non-linear load, increasing user and supplier costs. The power AC signals rectification processes must be periodically reviewed, to find the best solution for users and suppliers.

Basically, an UPS is made of a rectifier, a battery rack and an inverter. Under the on-line configuration, the rectifier takes the 60 Hz alternating power from the power supply system (network operator or emergency plant) and turns it into direct power, thus feeding the other two systems, e.g. the battery rack and the inverter. The battery rack is charged and the inverter turns this direct power into alternating power to feed the sensitive load. Depending on the conversion technologies that are applied, an UPS might become a current and voltage harmonic generating source. See Fig. 1.

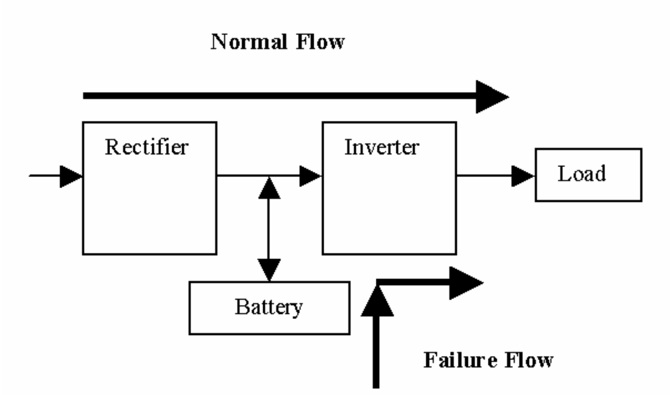

Fig. 1: UPS power flow and basic structure.

Rectifiers are traditionally provided with SCR, which perform the low-frequency conversion processes creating a distortion in the current wave and a low power factor. This distortion disturbs the power system for it increases the loss in wiring, transformers, power plants and capacitor banks, to the point of changing those systems into inefficient, unreliable and non-safe sources when used in sensitive systems with critical processes.

The existence of current and voltage harmonics disturbs the sensitive electronic loads and it is the reason to look for state-of-the-art steady voltage sources. This effort is outstanding in inverters using insulated gate bipolar transistors (IGBT) in UPS' inverters since this way it is possible to receive sine voltage signals with low voltage harmonic distortion, no matter the type of the load distorted current wave.

III. POWER SEMICONDUCTORS AND CONTROLLED DEVICE MODULATION

Rectifiers and inverters, among other power applications, use semiconductors to complete their respective processes.

For medium and low voltage power applications, various types of elements are used that allow handling the signals. Among such power elements there are SCRs, BJTs, MOSFETs, GTOs and IGBTs.

Insulated gate bipolar transistors (IGBT) are power transistors combining BJT and MOSFET features: They have a MOS transistor input structure that allows for fast control and simple connection, and a bipolar transistor output structure that allows handling a high voltage current.

Based on these special features, power electronics has focused on medium and low range IGBT devices as an alternative over other technologies. Advantages of using IGBT are:

• High current density (higher as compared to a BJT)
• Low drop voltage
• Smaller device
• IGBT may be easily voltage-controlled on a MOS type input, as compared with current-controlled devices

Due to its outstanding features, this device allows for fast operation without overheating or important loss of power. This new technology improves the efficiency of rectifiers and inverters.

There exist controlled (IGBT, MOSFET, SCR, etc) and non-controlled (Diodes) power semiconductor devices. Among the many modulation types for controlled devices, the pulse width modulation is far the most advantageous, though it is necessary that the device allow for fast operation features as explained in Fig. 2.

Controlling with pulse width modulation is more advantageous than other types of controls for it reduces the current harmonic distortion. The angle of lag or suppression angle control controls de devices using only one pulse for incoming power, which allows for harmonic smallest reading from the third harmonic (typically used with SCR). Signal filtering and treatment shall be more effective as the harmonic originated in the device be higher-sequenced.

IV. SIMULATIONS

We know many types of rectifiers that are used on different applications. However, even if they are efficient in converting the AC input voltage into a DC voltage, they critically distort the power input signals. From the power quality viewpoint, it is important to keep the sinusoidal current and voltage modes as undisturbed as possible at the rectifier input or at the power distribution node.

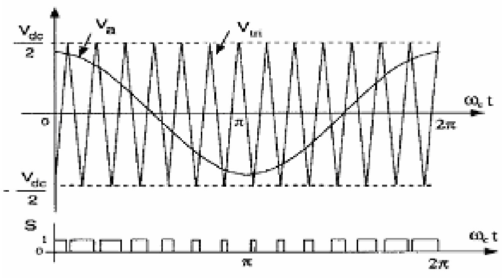

Fig. 2: Sinusoidal pulse width modulation SPWM obtained from comparing a sinusoidal wave to a triangular wave.

Devices connected to the system are in risk of damage should there exist a distorted current wave in the power network. There also are a number of reactive power losses in each of the devices connected, global device overheating and neutral leakage currents.

Various techniques are used to correct the mentioned problems, such as using isolation transformers on both sides of the devices, thus interrupting the DC power flow through the lines and preventing sharp current changes. Filters are also used at device input to temper the wave, though they displace the phase in relation with the carrier. These solutions may be very expensive.

A. Single-phase rectifiers with capacitive load

Rectifier circuit in Fig. 3 is a critical case where rectifier input current gets distorted due to the condenser charge and discharge on the DC side, as shown in Fig. 4.

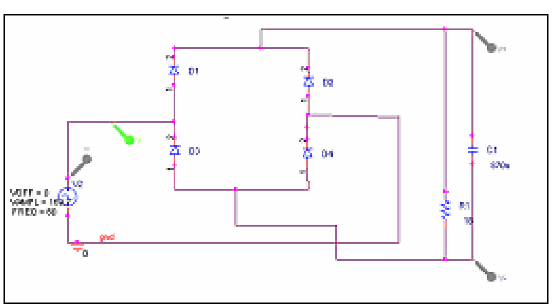

Fig. 3: Diode 1F Rectifier with capacitive load.

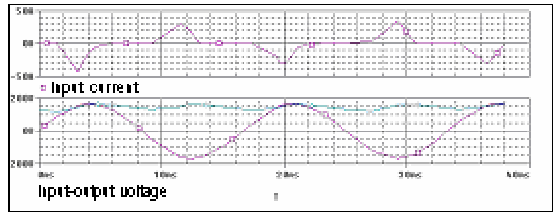

Fig. 4: Input power wave shapes and input and output voltages in a single-phase rectifier with capacitive load.

The input power harmonic spectrum is that shown in Fig. 5.

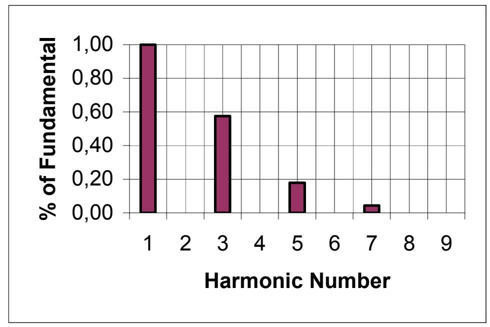

Fig. 5: Input I harmonic spectrum in a 1F rectifier with capacitive load.

B. Single-phase rectifiers with capacitive load and AC filter

To correct such a distorted harmonic spectrum, inductive filters are incorporated as shown in Fig. 6. Fig. 7 shows voltage and input power with inductive filter. Note that there is a phase displacement between the waves that results in the loss of power.

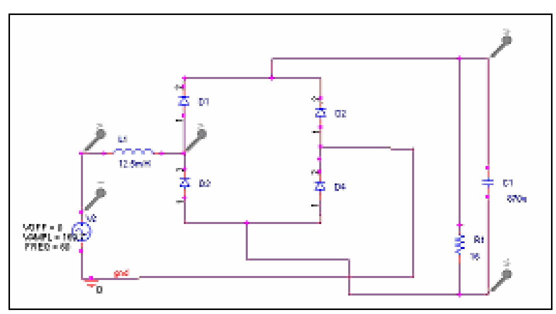

Fig. 6: Scheme of a single-phase rectifier with power diodes, input inductive filter and RC load.

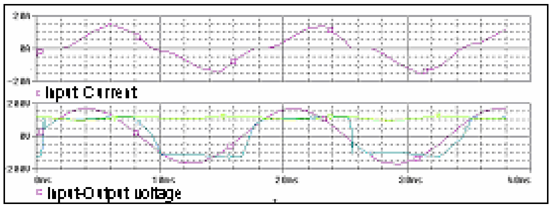

Fig. 7: I and V input and output wave shapes in a single-phase rectifier with AC filter and capacitive load.

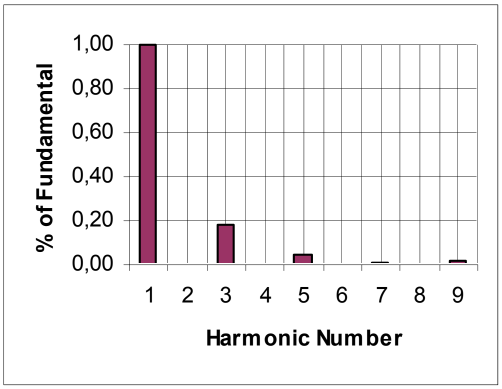

Fig. 8: I input harmonic spectrum in a 1F rectifier with capacitive load.

As you can see in Fig.s 5 and 8, there is an outstanding improvement in the harmonic spectrum when using an inductive filter.

C. Three-phase rectifier with capacitive load and AC filter.

The three-phase rectifier works in a way similar to the single-phase rectifier. Fig. 9 shows the connection diagram.

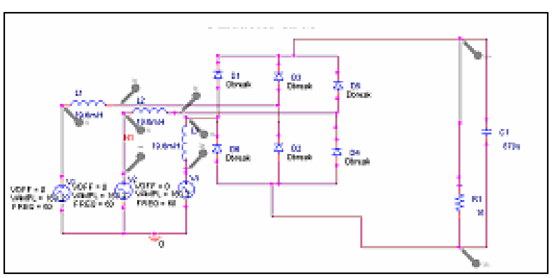

Fig. 9: 3 F controlled rectifier with power diodes, inductive filter and RC load.

Power is also distorted and phase displacement occurs under a three-phase situation, even if a filter is used to correct. There must be taken into consideration that the load value is fixed, and the filter shall not be efficient if the load changes.

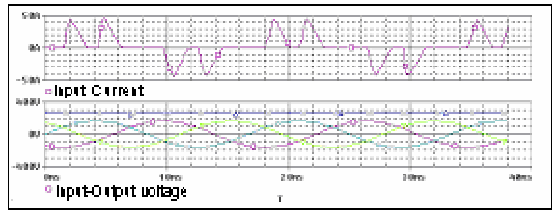

Fig. 10a: I and V input and output wave shapes in a three-phase rectifier without filter

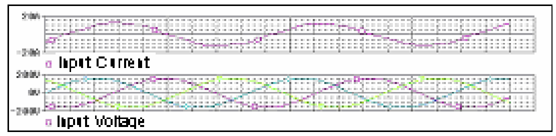

Fig. 10b: Input wave shapes and input and output voltages in a three-phase rectifier circuit with input inductive filter.

Please note that these harmonics have less than 10% of the main harmonic, which means it is a good rectifier. However, the power phase displacement results in important losses of power. This is one of the rectifiers used in most of equipment requiring a three-phase correction.

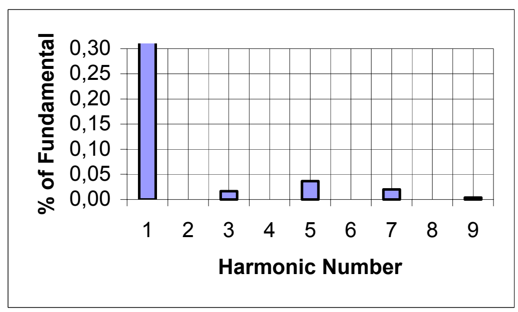

Fig. 11: Input power harmonic spectrum in a three-phase rectifier with capacitive load and AC filter.

D. Controlled three-phase rectifier with capacitive load and IGBT

These rectifiers, in Fig. 13, use PWM at each of the IGBT gates, reason why each gate is connected with a comparator sub circuit that generates the SPWM at 6 KHz with the appropriate phase for the device to enable its components for conduction purposes. Such a sub circuit is show in Fig. 12.

Output power results are also outstanding in the events of three-phase rectifiers with IGBT.

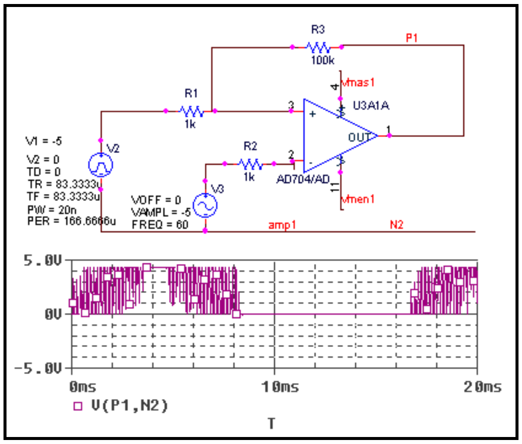

Fig. 12: SPWM generation circuit

As seen in Fig. 14, the power is fully phased with the input voltage and the harmonic spectrum, which means that harmonics are almost null without the need of using filters, as shown in Fig. 15.

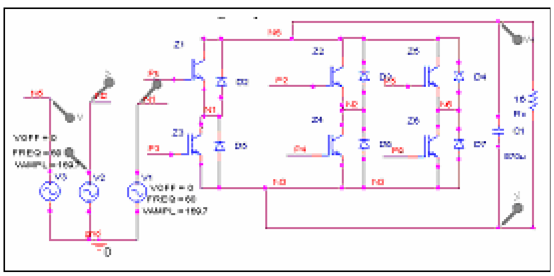

Fig. 13: Three-phase controlled rectifier with IGBTs and RC load

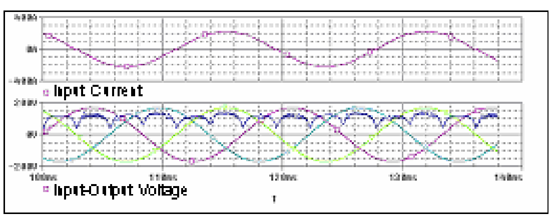

Fig. 14: V and I wave shapes in 3F rectifier with IGBTs.

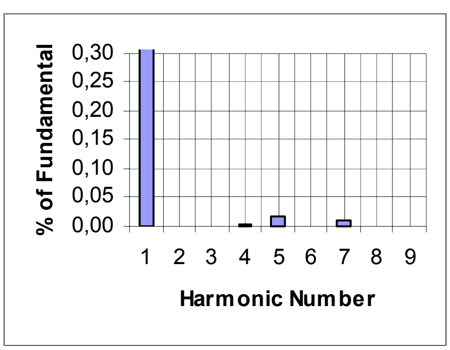

Fig. 15: 3F rectifier harmonic spectrum, using IGBTs and SPWM.

V. POWER QUALITY

From the power quality and electromagnetic compatibility viewpoint, it is important to have self-control power elements available that auto controls the various disturbances that may be present in the power signal. This situation is to be beard in mind not only for inverter technologies but also for rectifier technologies. At present, there exist rectifier sources that have developed new technologies, which allow controlling the power signal distortion without using large filters, for they use the same devices as used in inverters, e.g. IGBTs, thus controlling the power and voltage distortion.

Using these technologies results in wiring, ducts, switching, emergency plants, high-frequency filters, capacitor bank and losses of power savings. It also improves the power system reliability since no additional or external elements are required to achieve the expected performance.

For the above, it is important to take this behavior into consideration when analyzing the sensitive electronic load backup sources and the need to make them compatible with the respective power system.

VI. RESULTS

Simulated circuits have proved that using IGBTs and SPWM allow for an adequate voltage correction with minimum distortion and device input power. There is no power wave phase displacement, reason why the input power is best taken advantage of; this advantage is reflected in the power factor.

It is to be noticed that load multi-use does not disturb the shape or the power wave phase or input device voltage. No harmonic content is detected in input inductive or capacitive loads. In this sense, the rectifier does not react to the specific load placed.

Table 1 shows the results, in terms of power factors as well as voltage and power THD at device input level, of simulations presented herewith, and others not disclosed due to the paper length but which are part of the main work.

TABLE I
COMPARISON OF QUALITY MEASURE FACTORS FOR SOME CIRCUITS SIMULATED USING ORCAD. PF IS TOTAL POWER FACTOR; DF IS DISPLACEMENT FACTOR AND THD IS TOTAL HARMONIC DISTORTION IN INPUT CURRENT AND VOLTAGE.

Description	THD (%) V	THD (%) I	DF	PF
Single-phase rectifier with inductive load	0.30	38.55	0.99	0.54
Controlled single-phase rectifier with inductive load	0.01	30.53	0.98	0.67
Single-phase rectifier with capacitive load	6.61	77.08	0.96	0.36
Single-phase rectifier with capacitive load and choke	1.36	21.55	0.82	0.58
Three-phase rectifier with inductive load	0.53	24.92	0.99	0.69
Three-phase rectifier with capacitive load	0.19	89.18	0.99	0.42
Three-phase rectifier with capacitive load and choke	0.47	5.42	0.78	0.70
Rectifier with IGBT and PWM	**THD (%) V**	**THD (%) I**	**DF**	**PF**
Single-phase rectifier with inductive load	0.01	6.72	1.00	0.90
Single-phase rectifier with capacitive load	0.01	6.72	1.00	0.90
Three-phase rectifier with inductive load	0.01	2.00	1.00	0.97
Three-phase rectifier with capacitive load	0.01	1.99	1.00	0.97

VII. CONCLUSIONS

- Using IGBTs with SPWM allows to satisfactorily correcting the input voltage and power signals, without disturbing the device input power shape. This reduces the effort to control de harmonics produced by the rectifier circuits' non-linear loads.
- Correction using IGBT and SPWM technologies provides a better power factor and lower total harmonic distortion at rectifier input level, allowing for a better power consumption and a correction adjusted to requirements.
- Since no additional solutions are required to control the harmonics in the distribution node, it is not necessary to incur additional costs originated in higher power consumption and the use of filters or transformers to protect the distribution systems, while protecting the UPS load.

VIII. REFERENCES

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IX. BIOGRAPHY.

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