Potential Of Power Electronics to Improve the Power Quality of Network Grid

Abobkr Hassen. R. Mohamed[1], **Saleman Abobker Amer**[2]

[1,2]Electrical Department of the Higher Institute of Sciences and technology, Aljofra-sokana, Libya

Abstract

This study deals with voltage drop characterization of transmission systems by using power electronics circuits supplied from embedded generation.

Many grid-connected power electronic systems, such as STATCOMS, UPFCs, and distributed generation system interfaces, use Voltage Source Inverters (VSI) connected to the supply network through a filter. This filter, typically a series inductance acts to reduce the switch harmonics entering the distribution network an alternative filter is an LCL network, which can achieve reduced levels of harmonic distortion at lower switching frequencies and with less inductance, and therefore has potential benefits for higher power application. However, systems incorporating LCL filters require more complex control strategies.

This dissertation proposes a robust strategy for regulating the grid current connected via an LCL filter. The strategy integrates an outer loop grid current regulator with inner capacitor current regulation to stabilize the system. An asynchronous farm PI current regulation strategy is used for the outer grid current control loop. Linear analysis, simulation, and experimental results are used to verify the stability of the control algorithm across a range of operating conditions and finally, expressions for "harmonic impedance" of the system are derived to study the effects of supply voltage distortion on the harmonic performance of the system.

Keywords: Power, Voltage, Grid, Network, Systems.

1. Introduction

Power electronic converters are now used in many grid-connected applications including STATCOMs, USFCs, and active interfaces for distribution generation systems. These converters are commonly based on a voltage source inverter (VSI) connected to the supply network.

They are operated to achieve the objectives of power flow regulation to power factor optimization by regulating the current into the grid using schemes such as synchronous frame controllers, predictive current deadbeat control, or hysteresis-based strategies. Typically, simple series inductors are used as the filter interface between the VSI and the grid network. However, these filters require high switching frequencies to acceptably attenuate switching harmonics, particularly in weak-grid applications where supply is sensitive to these harmonics.

In contrast, the alternative LCL form of low-pass filter offers the potential for improved harmonic performance at lower switching frequencies, which is a significant advantage in requiring higher-power applications. However, systems in-corporating LCL filter complex current control strategies to maintain system stability, and are more susceptible to interference caused by grid voltage harmonic impedance presented to the grid.

2. Modeling of the electrical power

❖ Transmission line

The main power corridor in a power system is the overhead three-phase power transmission line. It could be expected that the circuit system would be simple as the lines are ideal conductors. However, three different phenomena produce effects that the engineer must be aware of. In order of importance, they are the series voltages induced by the magnetic fields surrounding the conductors, the shunt displacement currents resulting from the electric fields between conductors, and the ohmic resistance of the conductor material. [1] A fourth but less important effect is the leakage conduction current that flows through any contamination that may build up on the insulators. This is small enough to be neglected.

Overhead neutral lines are electrically connected to the tower and therefore grounded. Their main role is to provide lightning shielding for phase conductors but in addition, they also carry zero sequence and harmonic current that helps to maintain balanced sinusoidal voltages.

Generally, they are steel or aluminum and have a diameter of about 1cm. Phase conductors are much larger with a diameter of about 5 cm and typically constructed of stranded aluminium wire surrounding a stranded steel cable to increase tensile strength. Occasionally more than one bundle comprises a phase. All phase conductors have no insulated covering to allow heat to dissipate. The phase conductors are insulated from each other and from the tower by suspension from insulators.

Some of the reasons for deciding to build a new line are as follows: a common situation is that the growth of the electrical load in an area has almost reached the thermal or stability limits of available lines. Studies in a particular location might have shown that system reliability has fallen below acceptable levels. Additional lines in an area might improve the transient stability characteristics of a generating station or new generation sites at remotelocations may require additional lines. As well as this, additional lines allow for more flexibility in the system.

Once it has been decided to build a new line the basic considerations are the power rating and the voltage to be used. As understood, the line capacity is related to the length and voltage rating to; the capacity varies as the square of the voltage, whereas the line coat varies roughly linearly with the voltage. Only standard voltage levels are to be considered here because of the availability of equipment. For any particular power level and the pre-determined line length, a specific voltage class will prove to be an economic optimum. The greater the required capacity or the line length, the higher the optimum voltage class.

If voltage and power ratings have been selected for proposed lines of a known length a number of other decisions must be made. These include the number, size, and spacing of conductors per phase bundle. The critical agents here are the corona and the effects of line impedance. The phase-to-phase spacing must be selected. The number, location, and conductor type for overhead neutral lines must be determined bearing in mind that lightning shielding is the major consideration. The level of insulation must be selected, deciding how many suspension discs are to be used in the insulators. When the complete weight of the line is calculated then the local conditions of weather, climate, and topography must be assessed; in particular, the worst icing and wind conditions within reason must be estimated because this must be calculated for the tower load. Architectural aesthetics should be considered particularly in populated areas. Tower width relates to available right-of-way, and the decision to use guyed or free-standing towers must be made. Overhead minimum clearances for railroads, highways, structures, vegetation, and the ground must be established; these dimensions fix tower height, along with tower spacing and permissible conductor sag. Possible conductor motions set up by varying wind strengths must be allowed for and minimized. All the above factors must be considered and satisfactorily accounted for with an economically acceptable design. Some of the electrical characteristics important in the design and operation of a transmission system will be discussed below.

First, it is important to develop a circuit model for this drive and this must start with the most important parameter, the line inductance. Here, a problem in notation arises that could potentially cause confusion. The nature of the model in the line impedance and admittance expressions per unit length is first derived, with the effect of the line length dealt with later. It is difficult to develop symbolism that distinguishes per unit length in all cases so "Z" is the parameter measured in ohms/meter. No confusion will result if the measurements are read carefully; to help make the necessary distinction, the units are named on the right of the equation when necessary. The necessary equations that are derived are rigorously applicable only to a line of infinite length. However, for power applications, end effects are negligible [1].

❖ Voltage sags and interruption of the supply

When faults occur in the system, the customer voltage drops below its nominal value on one or more phases. Voltage sags of up to 30% (remaining voltage is 70% of nominal voltage) are much more common than complete outages or complete sags. Many last for some 100ms up to multiples of seconds or even for a longer time until the fault is cleared and re-closing of the power in-feed occurs. The interruption time depends on any protection schemes or the network configuration. A more reliable supply with less probability of interruption or shorter interruption times determines a higher investment cost [2].

❖ Voltage sag analysis

A sudden voltage drop is known as a Voltage sag. These occur while the load remains connected to the supply. Nearly all disruptive voltage sags are caused by faults or by a sudden major load increase [3] this paper concentrates on sags associated with faults on the electrical distribution feeder. In those cases, the voltage sag occurs when short circuit currents flow and then return to normal as soon as the fault current is interrupted by a fault-clearing device. Physically it is possible for the fault to be miles away from the sensitive load/customer but electrically close enough to create a visible sag in the voltage. The actual distance does not translate directly into the electrical distance. It is absolutely necessary to analytically calculate the magnitude of the sag for each fault event. This calculation requires knowledge of networks, fault-related information, and possibly the per-fault voltage. Some simple examples are presented for detailed calculation; a short circuit program can be used for sag analysis.

The necessary network data can be obtained from the database of the distribution system. Generally, this data includes switch status network connections, loading conditions, line section impedance, transformer data, and protection device all of which are basic data for the analysis of the power system. Transformer connection data are also critical for sag analysis. A particular transformer connection may help to reduce a certain set of sag problems for specific equipment [4].

The faults-related data are stored in the outage historical database and should include fault locations, fault impedances, and the time they occurred. Each fault event, as reported by field crews, can result in one or more voltage sags.

With regard to per-fault voltages, it is normal that this data is not available unless a SCADA (supervisory control and data acquisition) system with history has been implemented. If a SCADA has a history database, the per-fault voltages will have been recorded when the fault occurred. However, in most cases, these data are not available. The IEC 909 standard recommends the per-fault voltages to be 1.1 p.u [5] in the VSAG.

In order to provide a more accurate solution, a power flow solution with appropriate seasonal loading parameters is used as the per-fault condition.

❖ Embedded Generation

Electricity generation is connected to the distribution network rather than to the high-voltage National Grid. Embedded generation is typically a smaller generation such as combined Heat and Power (CHP) or renewable generation: small hydro, wind or solar power generators fall into this class [7]. The development long long-term environmental target is important for embedded generation.

The issues:

Today's distribution network operates passively delivering power from a transmission network, through the distribution network to the end customer.

They have been built, and operated and are operated and regulated, to work in this way. Substantial embedded generation would require more active distribution networks which Allow electricity to flow in two directions to the electricity used for consumption in the Home or business, and on to the network when the user is exporting excess electricity.

3. Power Quality (PQ)

PQ is defined as any power problem manifested in voltage, current or frequency deviation that results in malfunctions of customer equipment [8]. It has been a growing concern for both utilities and customers over the past two decades. This issue has resulted from the proliferation of power quality sensitive equipment, such as microprocessor-controlled devices, computers, variable speed drives, and semiconductor devices. As a consequence, power quality disturbances, which have been considered normal for many years, may now cause disruption to the industrial power system with a resulting loss of production. Power quality disturbances such as momentary under-voltage (sag), over-voltage (swell), surges, and harmonics have been identified as the major sources of power quality problems [8]

Power quality is a whole new area within electrical engineering where fundamental research involves basic concepts and definitions; modelling and analysis, measurement and instrumentation; sources; effects, and mitigation. The ultimate goal of power quality research is to maintain a satisfactory quality of the electric supply. See [9, 10, and 11] for a general review of the subject; this also covers research guidelines and new emerging power quality standards and guidelines. Several U.S. and European standard efforts are shown in [12.13]. Many PQ research activities were aimed at capturing the characteristics of PQ disturbances and identifying the current PQ level in certain areas. Two major projects are the CEA National Power Quality Survey [14] and the EPRI Power Quality Survey [14]. In 1991 the Canada Electrical Association (CEA) launched a three-year Canada National power quality survey. Twenty-two utilities were involved and 550 sites were monitored. Some of the data collected has been analyzed and results indicate the frequency of sags that industrial and commercial customers have reported [16]. Between 1990 and 1995 the Power Electrical Research Institute (EPRI) undertook a survey on PQ levels across the continental United States [17] in which twenty- four utilities took part. In the initial stage of this survey a new monitoring device known as BMI8010 was designed. A data management system known as PQ view has also been developed which is aimed at tackling the enormous amount of data (22GB/per year).

❖ Classification of PQ Disturbances:

1) **Voltage Sags**: Momentarily short duration (0.5-30 cycles) decrease of the rated voltage (0.1-0.9 Pu). This is of short-term, few-cycle duration, a drop in voltage in the order of more than 10% to less than 90%. Typically it lasts from 0.5 cycles to a minute. Voltage sags result from the voltage drop, from starting big motors across the line, or from a fault on an adjacent power line [18]

2) **Voltage Swells:** Momentarily short duration (0.5-30 cycles) increase of the rated voltage (1.1-1.3pu). This is a short-term increase in voltage of a few cycles duration. The magnitude of the increase is more than 10% and less than 80%. A swell can result from a single line-to-ground fault which then raises the voltage on the other phase. It can also result from dropping a large load or energizing a capacitor bank [18]

3) **Transients:** These are high amplitude, short duration (<0.5 cycles) voltage disturbances

This is a sudden, bidirectional, non-power frequency change known as ringing. For high-frequency ringing over 500 KHz of 1-us duration and for 5-500 KHz ringing with tens of ms duration, it is likely to be the results of either the system response or the load response to an impulsive transient. With a frequency of fewer than 5 KHz and 0.3-50µs duration, it could have one of a number of causes [18].

4) **Voltage unbalances:** This is a variation of magnitude and/or phase angle from different phases.

In a three-phase system, significant differences in phase voltage indicate a problem with the system or a defect in load. Voltage unbalance can cause three-phase motors and other three-phase loads to experience poor performance or premature failure because of mechanical stresses in motors due to lower than normal torque output, higher than the normal current in motors and three-phase rectifiers, and the unbalanced current will flow through neutral conductors in a three-phase Wye system.

Unbalance is tracked in percentages. The negative sequence voltage (Vneg) and zero sequence voltage (Zero) together identify any voltage asymmetry between phases. Using a power quality analyzer to do the mathematics, high percentages indicate high unbalance. European Union power quality standard EN50160 requires Vneg to be less than 2 percent.

Table 1: Causes and Effects of PQ Disturbances

Disturbances	**Typical Causes**	**E effects**
Sags and Swells	Faults,motor starting,lightning strike	Computer system interruptions ,motor stalling
Transients	Load,lightning, capacitor bank	System over voltages insulation failures

	switching	malfunction Of sensitive electronic devices
Harmonic Distortion	Power electronics, arcing device, satiable device	Capacitor blowing, transformer heating/ failures, beaker Nuisance trip, protective relaying errors

4. Effect of transformer connections in the distribution system

Voltage sag seen by the customers is not only influenced by fault locations and fault types but also by the transformer connections. The decrease of the voltage magnitude and the phase angle deviation are a function of the connection of the transformer between the load and the system. This phenomenon is illustrated.

5. Tap-changing transformers

Tap-changer transformers are simply transformers whose turns may be changed by changing the tap set to either off-load or on-load. The voltage change between taps is normally only about 1.25% of the nominal voltage to avoid large voltage disturbances. By changing the transformer turns ratio, the voltage on the secondary side is altered to achieve voltage control. Tap-changers are the most popular method of voltage control at all voltage levels. Tap changers are the most cost-effective way of regulating the output voltage when the input voltage has a sag condition that exists for a relatively long period of time. It is possible to vary the output voltage by changing taps located on the primary or secondary side of a transformer. Most existing tap changers use mechanical moving parts to change the tap location. Usually, three or four cycles are needed to move the mechanical switch to the desired position. Therefore, its response is relatively slow [30]. To overcome this problem, thrusters have been used recently to replace the mechanical parts of the tap changer.

6. Power electronic converters

Power electronic converters are currently used to interface some forms of renewable generation and energy storage devices to distribution networks, and their use is likely to increase in the future. The development of these converters is benefiting from the rapid advances in power semiconductor switching devices and the progress being made in the design and control of variable-speed drives for large motors. One obvious application of power electronic converters is to invert the DC generated from energy sources (photovoltaic, fuel cells, or battery storage) to 50/60 Hz AC. however, converters may also be used to decouple a rotating generator from the network and so potentially increase the efficiency of the operation of the prime mover by ensuring it operates at its most efficient speed for a range of input power. This is one of the arguments put forward to support the use of variable-speed wind turbines. It is now being proposed for some forms of small hydro generation. Another advantage of variable-speed generating operation is the effect of the variable-speed generating set to store energy during transients. However, large power electronic converters do have a number of disadvantages including (I) significant capital cost and complexity, (II) electrical losses (which may include a considerable element independent of output power), and (III) the possibility of injection of harmonic current into the network [31].

Operation is possible at above and below synchronous speed. These slip-recovery systems were used on the multi-megawatt prototype wind turbines constructed as part of national research programs in the early 1980s. In general, these turbines did not perform well for a number of reasons not connected with the variable-speed converter equipment, and the concept was not pursued. However, recently commercial 1.5 MW 60m diameter wind turbines have been offered for sale with IGBT (insulated gate bipolar transistor_PMW (pulse width modulated) converters in the rotor circuits. A very narrow speed range is also possible using a wound rotor induction machine by mounting a controllable resistor on the rotor. Still, in this case, the slip energy is not returned to the network but lost as heat.

7. Simulation circuit

1) The first step is steady state

A- The first case represents a single-line diagram before the voltage dip.

To study the effect of the power quality on the network before voltage dip and also no load, in this case, found the system is steady state, however, it will be seen the next step after this step.

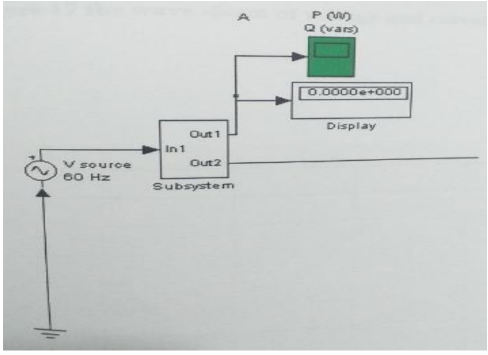

Fig 1: Modelling of Simulation at steady state

When:
P=8.1821x10*6 MW
Q2=2.9978x10*6 MVAR
V=13500 V

B- The second case represents single line diagram after voltage dip.

can BE seen as the Impact of voltage dip on power quality found the real and reactive power in this case lower than the first case due to power loss in the transmission line and also a large load in the end-of-system power quality effect due to the voltage changing to improve the power quality in the system what exactly do to improve this the power quality.

When:
P-6.9663x 10*6 MW
Q=2.0899x 10*6 MVAR
V=8x 10*3 KV

2) Second step connect the embedded generation with booster transformer

A)-First case the effect embedded generation connect with booster transformer before Connect transmission line or any load in power system found the real and reactive power Sudden increase due to voltage supply but less than the steady state

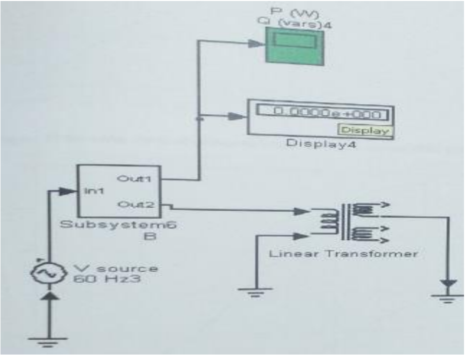

Fig 2: Modelling of Simulation at power system connect the (EG) with (BT)

B)- The second case in this step has connected transmission line two between the booster transformer and bus bar between loads and the first transmission line the booster transformer compensator voltage drop in the transmission line to keep the voltage in the bus bur equal to the voltage of embedded generation to keep the system steady

8. Results

At the steady state

Performing a single-phase analysis

1- The real power in the two loads are P1 =10x10*6 MW

2- Reactive power in the two loads are Q1=3x10*6 MVAR

3- The voltage loads are 13500V

4-the complex power in the load S1=P1+JQ1

Table 2: The First Case

Node	Calculation	Simulation	Different S-C	ERRO= (S-C)/S	%
PA	8.194x10*6 MW	8.1821x10*6MW	-11900	-0.00145	-0.145
QA	2.98x10*6MVAR	2.9978x10*6MVAR	17800	0.00593	0.593
PB	6.982x10*6MW	6.9663×10*6 MW	-15700	-0.00225	-0225
QB	2.073x10*6MVAR	2.0899x10*6MVAR	16900	0.000808	0.0808
PC	3.488×10*6 MW	3.4832x10*6 MW	-4800	-0.0013	-0.13
QC	1.04×10*6MVAR	1.0449x10*6MVAR	4900	0.00466	0.466
PD	3.488x10*6M W	3.4832×10*6 MW	-4800	-0.0013	-0.13
QD	1.04x 10*6MVAR	1.0449×10*6MVAR	4900	0.00466	0.466
VOLTAGE	11268.69 V	11268 V	-0.69	-0.00006	-0.006

Connect the embedded generation and transformer

Table 3: The Second Case After connect The Embedded Generation with Booster Transformer

Node	Calculation	Simulation	Different S-C	Erro=(S-C)/S	%
PA	7.614x10*6M W	2.9920x10*6MW	-766500	-0.001	0.1
QA	3.025Mx10 6 VAR	1.3922×10*6	-266700	-0.0976	9.76

		MVAR			
PB	6.25×10*6MW	1.5704×10*5 W	-23710	-0.00363	0.363
QB	2.745x10*6MVAR	1.4682x10*5 VAR	14830	0.07	7
PC	0.6223x10*6MW	1.7551×10*6MW	-9500	-0.00145	0.145
QC	0.265×10*6MVAR	8.7243×10*6 MVAR	-6100	-0.00311	0.31
PD	3.604x10*6 MW	6.8878x10*3KW	-3800	-0.00105	0.105
QD	-1.076x10*6MVAR	2.8274x10*3 VAR	-8100	-0.00751	0.751
PE	3.604x10*6 MW	8.8101x11110*5 W	-3800	-0.00105	0.105
QE	-1.076×10*6MVAR	4.3763x10*5 VAR	-3800	-0.00751	0.751
VOLTAGE	11467.895 V	11441 V	-26.895	-0.00235	0.023

9. Conclusions

Voltage sag is most important in the power quality of a power system. It can see the effect of voltage sag and power quality on the network, there is not a very big difference between the calculation and simulation in section one, only a tiny difference. The value is not accurate when calculating or using the instruments. In the first step in the calculation, found the real power and reactive power are higher because they are very close to the power supply and lower in the bus bar due to line power loss. This means power quality is affected by the voltage at the end of the system when the current is separate from the load. The real and reactive power is also reduced due to the current, meaning that the power quality is impacted by current and voltage. With this problem, found low power for customers.Table 2 tells us the real power and reactive power is bigger at the point of sending than at receiving, due to line power loss. The magnitude and direction of the flow of real power on a line depending on the phase angle between the sending end voltage and the receiving end voltage. Power flows from the end with the leading voltage to the end with the lagging voltage. The magnitude of power flowing down the line increases with an increasing phase angle. The magnitude and direction of the reactive power flow of on a line depends on the difference in magnitude between the sending end voltage and the receiving end voltage. Reactive power flows from the end with a higher voltage to the end with a lower voltage. The magnitude of reactive power increases with an increasing voltage difference. This problem affects the performance of the system. To avoid this problem, connecting the embedded generation very close to customers will improve the power quality, and also connecting a setup transformer with embedded generation to compensate for the voltage dip in a transmission line to keep the customers' voltage normal.

Table 3 tells us about changing the system. In this case found a very big difference between calculation and simulation, in real power and reactive power, but the voltage is approximately the same. If comparing the first and second steps, the value of the power quality is different. In the second case, the voltage improved for customers, and the real and reactive power also improved.

REFERENCES

1. power system analysis [CHARLESA. GROSS] chapter transmission line p-p 82-84.
2. power quality 97: 4th cone. (1997) June pp 199-208michi application of drive converter for improvement of the power quality distribution system 6242.240 ath (1997).

3. C.Becker et al, "proposed chapter 9 for predicting voltage sag Book" (dips) in revision to IEEE STD 493. The gold book IEEE Tran's on industry application vol.30, no 3, may/June (1994), pp.805-821.
4. M. Mcgranaghan, D. Mueller, and samotyj "voltage sagin industrial system" presented in the IEEE IASI &CPS Tech conf., may 1991.paper number 91 ch2990/091/0000-0018.
5. Short circuit current calculation in the three AC system, iec 909, first edition 1988.
6. Electric Power System (THIRD EDITION] chapter Distribution system P.p52-53.
7. www.ofgem.gov.uk[embedded generation summary]
8. Daniel J., Ward-, et al., "power quality-two different Perspectives", IEEE Transactions on power Delivery, vol.5, no, July (1990).
9. Brent M Hughes, ET “D distribution customer power quality Experience” IEEE Transaction on industry Application, vol29.No 6, November (1993).
10. Domijan G.T.Heydt and A.P.S.Meliopoulos. "DIRECTION OF Research on electric power quality", IEEE Transaction on power Delivery Vol.8, No 1, January (1993).
11. Wilson E Kazibwe, et al "power quality: a Review Guidelines", IEEE Computer Application in power January (1990).
12. Edward Reid, "Power Quality Issues- Standards and Guidelines", IEEE Transactions on Industry Applications Vol.32, (1996).
13. Robert E. Jurewicz, "Power Quality Study-1990-1995", international telecommunication energy conference (1990), p443-445.
14. Mark McGranaghan, "voltage sag in industrial system", (1991) IEEE Industrial and Commercial Power System Technical Conference.
15. Chandrasekran, Ashok sundaram "unified software approach to power quality assessment and evaluation, southcom conference record (1994).
16. Don O.Koval "power system disturbance patterns IEEE Transactioncations on industry application, vol 26, No 3, May (1990).
17. Don O.Koval and M.Brent Hughes, "Canadian National power quality survey: frequency of industrial and commercial voltage sags", IEEE Industrial and Commercial Tech.Conference (1996).
18. Oliver, J.A, Lawrence, Ranerjee B; B Industry application mayzinn IEEE Volum8, Issue 5 sept 2002 pp 21-30.
19. William W. Dabbs, et al, "Probing Power Quality Date", IEEE Computer Application in power V7.No2 April (1994).
20. Brent M. Hughes, et, Didtribution Customer Power Quality Experience" IEEE T transactions on Industry Applications, Vol 29.No6, November (1993).
21. Wenyuan Xu, ET, "Multiphase Harmonic Load Flow Solution Technique", IEEE Trans.on Power System, Vol6, No 1 February (1991).
22. Loredana Cristaldi, Alessandro Ferrero "Harmonic Power Flow Analysis for the Measurement of the electric power quality".
23. Stephen M.Williams, "Harmonic Propagation on an Electric Distribution System: Field Measurement Compared with Computer simulation", IEEE Trans on Power Delivery, Vol. 8, No2, April (1993)
24. G.A.Hazza, M.H.J.Bollen, al "influence of Generation on Voltage sags", Universities Engineering Conference, Sept (1997)

25. Sioe T.Mak, "propagation of transients in a distribution network" IEEE Transactions on Power Delivery Vol 8, No 1 JAN (1993), p 337-345
26. Washington L.A. Veves, Hermann Q, Dommel and Wilsun Xu m", practical Distribution Transformer Models for Harmonic Studies" IEEE Trans. On PowerDelivery, V.10, No 2, April (1995).
27. Lisa M.Anderson, et al "The effects of Power -line. Disturbances on consumer Electronic Equipment IEEE Transactions on Power Delivery, Vol.s, No2, April (1990).
28. Wagner V., grebe T., kretschmann R., Morgan L., prics. A.: power system compatibility with industrial process equipment IEEE; industry applications magazine pp.11- 15january/February (1996).
29. [Electric power system third edition] [B.M.WEEDY].
30. F.Q. Yousef-Zai and D.Okelly.Solid. "State-on-load transformer tap chanceries proceeding Electrical Power Application" Vol.143.No 6, pp.481-491(1996)
31. Embedded generation [Nick Jenkins, Ron Allan Peter Crossley, Daniel Kirschen and Goran Strbac P.P127-129