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Original Research Paper

Engineering

EFFECT OF UNIFIED POWER QUALITY CONDITIONER IN SMART GRID OPERATION AND CONTROL

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ABSTRACT The Government of India is taking initiative in implementation of Smart Grid . Ministry of Power proposed the target year 2027. The present paper discussed power quality issues in smart grid and possible solution using Unified Power Quality Conditioner (UPQC). A simulation of proposed model is prepared in MATLAB SIMULINK using parameters of Madhya Pradesh Power networks. The system was studied under different fault conditions with and without UPQC. The results have been discussed and the effect of Unified Power Quality Conditioner in Smart Grid Operation and Control is examined.

KEYWORDS : Smart Grid, UPQC, Faults, Power System, Flickers, Harmonics

1. INTRODUCTION:

Even a few years back, the main concern of consumers of electricity was the reliability of supply. Here we define reliability as the continuity of electric supply. Even though the power generation in most advanced countries is fairly reliable, the distribution is not always so. The transmission systems compound the problem further as they are exposed to the vagaries of Mother Nature. It is however not only reliability that the consumers want these days, quality too is very important to them. For example, a consumer that is connected to the same bus that supplies a large motor load may have to face a severe dip in his supply voltage every time the motor load is switched on. In some extreme cases, he may have to bear with blackouts. This may be quite unacceptable to most customers.

There are also very sensitive loads such as hospitals (life support, operation theatre, patient database system), processing plants (semiconductor, food, rayon and fabrics), air traffic control, financial institutions and numerous other data processing and service providers that require clean and uninterrupted power. In several processes such as semiconductor manufacturing or food processing plants, a batch of product can be ruined by a voltage dip of very short duration. Such customers are very wary of such dips since each such interruption cost them a substantial amount of money. Even short dips are sufficient to cause contactors on motor drives to drop out. Stoppage in a portion of a process can destroy the conditions for quality control of the product and require restarting of production. Thus in this changed scenario in which the customers increasingly demand quality power, the term power quality (PQ) attains increased significance.

1.1. Impacts of Power Quality Problems on End Users

The causes of power quality problems are generally complex and difficult to detect. Technically speaking, the ideal ac line supply by the utility system should be a pure sine wave of fundamental frequency (50/60 Hz). In addition, the peak of the voltage should be of rated value. Unfortunately the actual ac line supply that we receive everyday departs from the ideal specifications. Table 1.1 lists various power quality problems, their characterization methods and possible causes.

There are many ways in which the lack of quality power affects customers. Impulsive transients do not travel very far from their point of entry. However an impulsive transient can give rise to an oscillatory transient. The oscillatory transient can lead to transient overvoltage and consequent damage to the power line insulators. Impulsive transients are usually suppressed by surge arresters.

Short duration voltage variations have varied effects on consumers. Voltage sags (also knows as dips) can cause loss of production in automated processes since a voltage sag can trip a motor or cause its controller to malfunction. For semiconductor manufacturing industries such a loss can be substantial. A voltage sag can also force a computer system or data processing system to crash. To prevent such a crash, an uninterruptible power supply (UPS) is often used, which, in turn, may generate harmonics.

The protective circuit of an adjustable speed drive (ASD) can trip the system during a voltage swell. Also voltage swells can put stress on computers and many home appliances, thereby shortening their lives. A temporary interruption lasting a few seconds can cause a loss of production, erasing of computer data etc. The cost of such an interruption during peak hours can be hundreds of thousands of dollars.

The impact of long duration voltage variations is greater than those of short duration variations. A sustained overvoltage lasting for few hours can cause damage to household appliances without their owner knowing it, until it is too late. The under voltage has the same effect as that of a voltage sag. In the case of a sag the termination of process is sudden. But normal operation can be resumed after the normal voltage is restored.

However in the case of a sustained under voltage, the process cannot even be started or resumed. A sustained interruption is usually caused by faults. Since the loss to customers due to any sustained interruption can be in the order of millions of dollars, it is necessary for the utility to have a good preventive maintenance schedule and to have agreements or regulations to encourage high supply reliability.

Voltage imbalance can cause temperature rise in motors and can even cause a large motor to trip. Harmonics, dc offset and notching cause waveform distortions. Harmonics can be integer multiples of fundamental frequency, fractions of the fundamental frequency (sub harmonics) and at frequencies that are not integer multiples of the fundamental frequency (interharmonics). Unwanted harmonic currents flowing through the distribution network can causes needless losses.

Harmonics also can cause malfunction of ripple control or traffic control systems, losses and heating in transformers, electromagnetic interference (EMI) and interference with the communication systems. Ripple control refers to the use of a 300Hz to 2500Hz signal added to distribution lines to control switching of loads such as hot water heaters or street lighting. Interharmonic voltages can upset the operation of fluorescent lamps and television receivers. They can also produce acoustic noise in power equipment. DC offsets can cause saturation in the power transformer magnetic circuits. A notch is a periodic transient that rides on the supply voltage. It can damage capacitive components connected in shunt due to high rate of voltage rise at the notches.

Voltage flickers are caused by arc discharge lamps, arc furnaces, starting of large motors, arc welding machines etc. Voltage flickers are frequent variations in voltage that can cause the light intensity from incandescent lamps to vary. This variation is perceived as disturbing by human observers, particularly in the range of 3 to 15 times per second. The voltage flicker can have adverse effects on human health as the high frequency flickering of light bulbs, fluorescent tubes or television screen can cause strain on the eyes resulting in headaches or migraines. The voltage flicker can also reduce the life span of electronic equipment, lamps etc. We can therefore conclude that the lack of standard quality power can cause loss of production, damage of equipment or appliances or can even be detrimental to human health. It is therefore imperative that a high standard of power quality is maintained. This book will demonstrate that the power electronic based power conditioning devices can be effectively utilized to improve the quality of power supplied to customers.

1.1.1 Power Quality Standards

Geneva based International Electrotechnical Commission (IEC) and Institute of Electrical and Electronic Engineers (IEEE) have proposed various power quality standards. A review of various standards is given in [1]. Table 1.2 lists some of these standards that are given in [1].

Table 1.1. Some power quality standards of IEC and IEEE

Phenomena	Standards
Classification of power quality	IEC 61000-2-5: 1995 [2], IEC 61000-2-1: 1990 [3] IEEE 1159: 1995 [4]
Transients	IEC 61000-2-1: 1990 [3], IEEE c62.41: (1991) [5] IEEE 1159: 1995 [4J, IEC 816: 1984 [6J
Voltage sag/swell and interruptions	IEC 61009-2-1: 1990 [3J, IEEE 1159: 1995 [4]
Harmonics	IEC 61000-2-1: 1990 [3], IEEE 519: 1992 [7] IEC 61000-4-7: 1991 [8]
Voltage flicker	IEC 61000-4-15: 1997 [9]

2. The Smart Grid

2.1 Introduction

Today's electric grid was designed to operate as a vertical structure consisting of generation, transmission, and distribution and supported with controls and devices to maintain reliability, stability, and efficiency. However, system operators are now facing new challenges including the penetration of RER in the legacy system, rapid technological change, and different types of market players and end users. The next iteration, the smart grid, will be equipped with communication support schemes and real-time measurement techniques to enhance resiliency and forecasting as well as to protect against internal and external threats. The design framework of the smart grid is based upon unbundling and restructuring the power sector and optimizing its assets. The new grid will be capable of:

2.2 Today's Grid Versus The Smart Grid

As mentioned, several factors contribute to the inability of today's grid to efficiently meet the demand for reliable power supply. Table 1.1 compares the characteristics of today's grid with the preferred characteristics of the smart grid.

TABLE 1.2. Comparison of Today's Grid vs. Smart Grid

Preferred Characteristics	Today's Grid	Smart Grid
Active Consumer Participation	Consumers are uninformed and do not participate	Informed, involved consumers—demand response and distributed energy resources
Accommodation of all generation and storage options	Dominated by central generation—many obstacles exist for distributed energy resources interconnection	Many distributed energy resources with plug-and-play convenience focus on renewables
New products, services, and markets	Limited, poorly integrated wholesale markets; limited opportunities for consumers	Mature, well-integrated wholesale markets; growth of new electricity markets for consumers
Provision of power quality for the digital economy	Focus on outages—slow response to power quality issues	Power quality a priority with a variety of quality/price options—rapid resolution of issues
Optimization of assets and operates efficiently	Little integration of operational data with asset management—business process silos	Greatly expanded data acquisition of grid parameters; focus on prevention, minimizing impact to consumers
Anticipating responses to system disturbances (self-healing)	Responds to prevent further damage; focus on protecting assets following a fault	Automatically detects and responds to problems; focus on prevention, minimizing impact to consumers
Resiliency against cyber attack and natural disasters	Vulnerable to malicious acts of terror and natural disasters; slow response	Resilient to cyber attack and natural disasters; rapid restoration capabilities

- Handling uncertainties in schedules and power transfers across regions
- Accommodating renewables
- Optimizing the transfer capability of the transmission and distribution networks and meeting the demand for increased quality and reliable supply
- Managing and resolving unpredictable events and uncertainties in operations and planning more aggressively.

2.3 Power Quality Problems in Dg Integrated Smart Grid Network

Electric power is the result of a production process and according to the Council of European Energy Regulators (CEER) [9] the quality of electric power supply should comprise in three main areas, where the power quality means the continuity of supply and voltage quality. Again, Green House Gas (GHG) emission and the Global Warming are the side effects of the conventional electric power production process. Therefore, developed countries are also trying to reduce their overall GHG emission by introducing and increasing the share of renewable energy into their electric grid system. Hence, the quality of power supply has become an important issue with the high penetration of DG systemseither connected to the smart grid or microgrid. As the solar, wind, micro-hydro are the most leading sources of DG systems therefore power quality problems related to these DG system along with diesel (one of the highest CO_2 emitter) have been identified and shown in Table 1.2.

3. Working Principle of UPQC

UPQC is the integration of series (APFse) and shunt (APFsh) active power filters, connected back-to-back on the dc side, sharing a common DC capacitor [10], shown in Figure 3. The series component of the UPQC is responsible for mitigation of the supply side disturbances: voltage sags/swells, flicker, voltage unbalance and harmonics. It inserts voltages so as to maintain the load voltages at a desired level; balanced and distortion free. The shunt component is responsible for mitigating the current quality problems caused by the consumer: poor power factor, load harmonic currents, load unbalance etc. It injects currents in the ac system such that the source currents become balanced sinusoids and in phase with the source voltages. The overall function of UPQC mainly depends on the series and shunt APF controller. A basic functional block diagram of a UPQC controller is shown in Figure 4. Here, the shunt APF injects the compensating reactive and harmonic current using hysteresis current controller and where as the series APF uses PWM voltage controller to minimize the voltage disturbances.

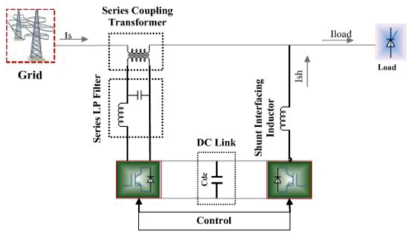


Figure 1 - Basic System Configuration of UPQC

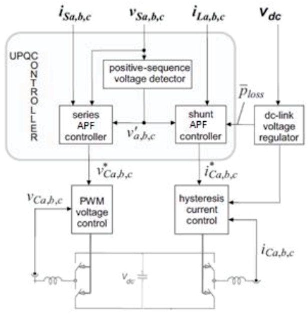


Figure 2 - Functional block diagram of a UPQC controller

4. Integration of UPQC with Smart Grid

Recent reports [4-8, 11, 12] show that significant research and development has been carried out on the application of UPQC to DG integrated network. As the UPQC can compensate for almost all existing PQ problems in the transmission and distribution grid, placement of a UPQC in the distributed generation network can be multipurpose. As a part of integration of UPQC in DG systems, research has been done on the following two techniques: DC-Linked and Separated DG-UPQC systems.

A. $(DG-UPQC)_{DC\text{-}linked}$

A structure has been proposed in [4-7], as shown in Figure 5, where DG sources are connected to a DC link in the UPQC as an energy source. This configuration works both in interconnected and islanded mode (shown in Figure 6). In Interconnected mode, DG provides power to the source and loads whereas in islanded mode DG (within its power rating) supplies the power to the load only. In Addition, UPQC has the ability to inject power using DG to sensitive loads during source voltage interruption. The advantage of this system is voltage interruption compensation and active power injection to the grid in addition to the other normal UPQC abilities. The system's functionality may be compromised if the DG resources are not sufficient during the voltage interruption conditions. Economical operation of the system can also be achieved by proper controlling of the active power transfer between the supply and DG source through a series APF [7]. The proposed system can also reduce the investment cost by nearly one fifth if the UPQC and DG are used separately [8].

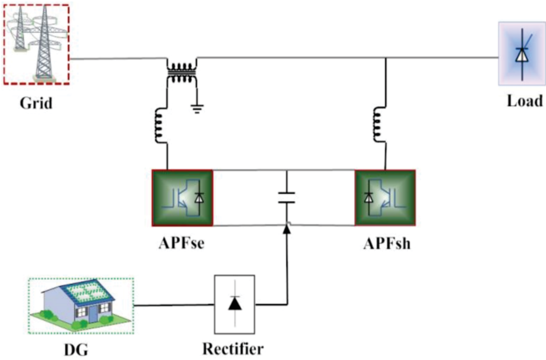


Figure 3 - UPQC with DG connected to the DC link

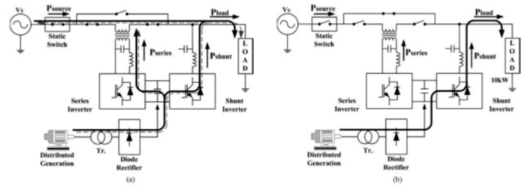


Figure 4 - $(DG\text{-}UPQC)_{DC\text{-}linked}$ System operation concept (a) Interconnected mode;

(b) Islanding mode [4]

B. $(UPQC-DG)_{Separated}$

A typical application of a UPQC might be to overcome the grid integration problems of the DG, such as the fixed-speed induction generator (FSIG) as investigated in [11] and shown in Figure 7. The FSIG fails to remain connected to the grid in the event of a grid voltage dip or line fault due to excessive reactive power requirement. The drop in voltage creates over-speeding of the turbine, which causes a protection trip. With the aid of the UPQC, this fault-ride-through capability is achieved, which greatly enhances system stability. Results show (Figure 8) that the UPQC is one of the best devices for the integration of wind energy system to the grid. In the case of a wind farm connected to a weak grid, UPQC can also be placed at the PCC to overcome voltage regulation problems [12]. In these separated systems, the series APF of the UPQC is placed near the DG side to conduct the voltage regulation by injecting the voltage in phase with PCC voltage. This type of UPQC is referred to as left shunt UPQC [13]. Based on the research study, in addition to the normal functionality of UPQC, some of the other advantages and disadvantages have been identified for the techniques which are given in Table 3.

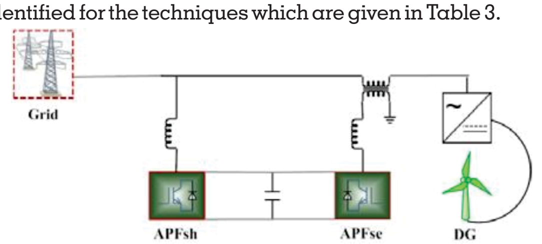
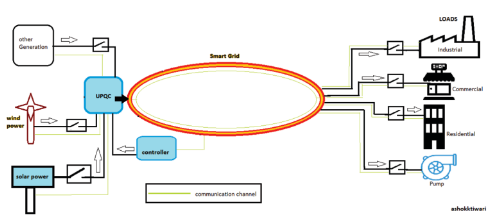


Figure 7 - Grid connected wind energy system with UPQC

5. Proposed Model



NETWORK PARAMETERS

1	33/11 KV CONVENTIONAL GRID SUBSTATION	2X10 MVA
2	WIND TURBINE-GENERATOR	700 V PH-PH rms , 5 KW X 100
	WIND POWER TRANSFORMER	700/11000 V, 20 MVA
3	Solar PV	960 V DC
	inverter filter	960 AC
	SOLAR POWER TRANSFORMER	960/11000 V , 1 MVA
4	Transmission Line	R/M=0.01273
		L/M=0.9337e-3
		C/M=12.74e-9
		Length 10 KM

5	Industrial load	6 MVA
	Domestic load	2 MVA
	Agriculture load	1 MVA

6. Research Methodology

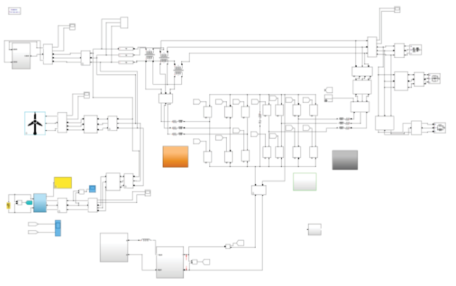
The MATLAB Simulation will be made for the proposed model which includes

- Simulation of UPQC using IGBT (FACT-PE)
- Controller, pulse generators
- Solar
- Wind
- DG
- breaker ,Transformer , line , load

The data of Madhya Pradesh power network shall be used in simulation study.

Emphasis will be given on integration techniques of UPQC in smartgrid or microgrid system along with their advantages and disadvantages. Again, the number of DG systems like Photovoltaic and Wind Energy Systems are now penetrating more into the smartgrid or microgrid as well as the numbers of non-linear loads are also increasing. Therefore, current research on capacity enhancement techniques of UPQC to cope up with the expanding DG or microgrid system will be also reviewed.

7. Simulation Results

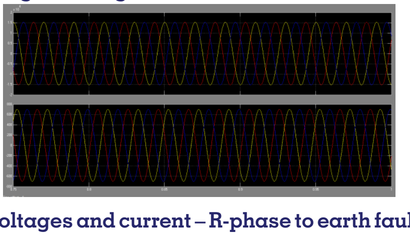


Grid voltage and currents:

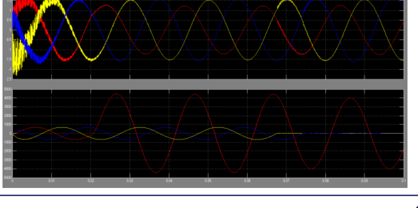
	Without UPQC						WITH UPQC					
	Grid Voltage			Grid Current			Grid voltage			Grid current		
	R	Y	B	R	Y	B	R	Y	B	R	Y	B
NORMAL	11000	11000	11000	618	621	619	11000	11000	11000	450	450	450
R-G FAULT	0	11000	11000	6321	700	700	0	11000	11000	4088	551	549
R-Y FAULT	0	0	11000	5516	5534	700	0	0	11000	4114	4161	700
R-Y-G FAULT	0	0	11000	6105	6119	700	0	0	11000	4211	4189	700
R-Y-B FAULT	0	0	0	6022	6112	6210	0	0	0	4501	4488	4490
R-Y-B-G FAULT	0	0	0	6266	6401	6328	0	0	0	4717	4754	4737

Waveforms:

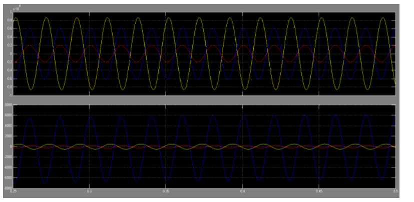
(1). Normal grid voltages and current



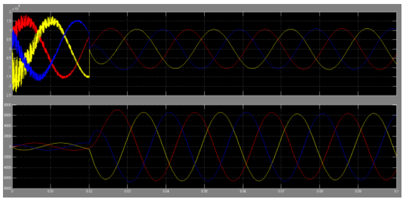
(2). grid voltages and current – R-phase to earth fault



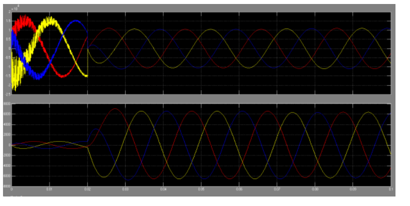
(3). grid voltages and current – R and Y phase fault



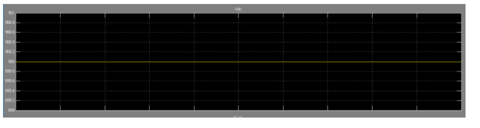
(4). grid voltages and current – R-Y- B fault



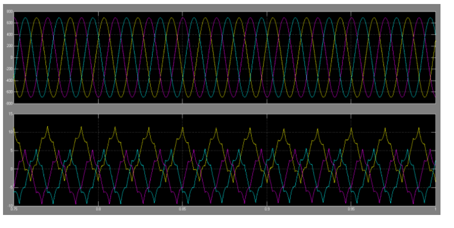
(5). grid voltages and current – R-Y- B to earth fault



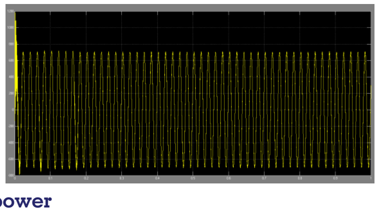
(6). SOLAR D.C.



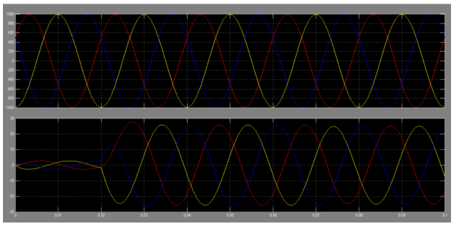
(7). SOLAR A.C.



(8). solar A.C. current after filter

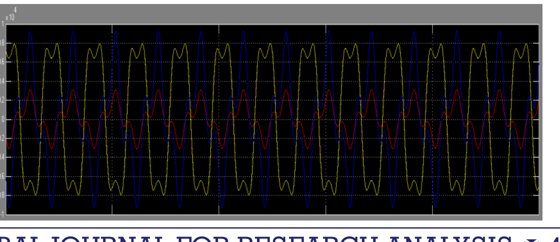


(9). wind power

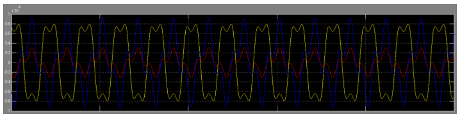


(10). HARMONICS REDUCTION:

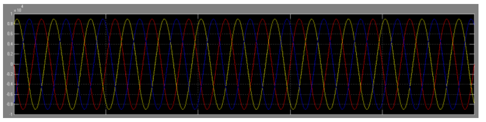
Generated harmonics waveform at source:



a. Effect of harmonics at load end without UPQC



b. Effect of harmonics at load end with UPQC



9. CONCLUSIONS

1) It is found that using UPQS in smart grid fault current reduces to certain extent.
2) It is found that load current also reduces using UPQC
3) It is observed that there is reduction in energy Loss using UPQC
4) Financial saving also observed up to much extent
5) It is also observed that due to reduction of harmonics the power quality is enhanced.

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