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Mitigation of Power Quality Problems using Unified Power Quality Conditioner in Paper Industries. A Case of Mufindi Paper Mills

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***Abstract*-With the increase of non-linear loads in electric power systems, power quality distortion has become a serious issue in recent years. In the paper industry, the main production line needs high quality electric power because it consists of several coupled motors working simultaneously together with precise speed. Mufindi Paper Mills experiences voltage variations problems caused by system faults, switching of power lines and capacitor banks, and large motor start-ups that result in undesired speed and stoppage of motors. These power quality disturbances cause paper rolls to break, poor paper quality, process downtime, revenue losses, idle work forces, and wasted energy during process restart and failure of equipment. Power quality problems have received a great attention nowadays because of their economic impacts on both utilities and customers. In this paper, a unified power quality conditioner (UPQC) was designed, modeled and simulated by synchronous reference frame theory. The proposed system is comprised of series and shunt inverters, which can compensate the Voltage sags and swells. Proportional Integral (PI) controller was used to stabilize the DC link voltage and balance the active power between the shunt and series inverters and the Phase-Locked Loop(PLL) generated reference signals. The proposed UPQC system was analyzed using MATLAB/SIMULINK software. The simulation results confirmed the correct operation of the proposed system**.

Keywords: Power quality, Speed, Non-linear loads, custom power devices

I INTRODUCTION

Power supply is a problem in developing countries including Tanzania, both in terms of availability and quality. With the increasing of non-linear loads in electric power system, power quality distortion has become a serious issue in recent years. Paper industries are among those industries affected by poor power quality. Mufindi Paper Mills (MPM) needs 22MW a day, but the supply authority (TANESCO) supplies only 13MW a day that leads to a deficit of 9MW per day. In addition, Mufindi Paper Mills experiences voltage variations problems caused by lightning strikes, switching of power lines and capacitor banks, system faults, and large motor start-ups. These power quality disturbances cause paper rolls break that require a long time to clean the machinery and resume production. Therefore, a study of the effects of poor power quality is essential for the paper mills. Power quality is the study of deviations in current and voltage waveforms from ideal sine waves. Power quality is the combination of voltage quality and current quality. Thus, power quality is concerned with deviations of voltage and/or current from the ideal [1].At the distribution level, power quality can be a combination of voltage quality and current quality. From the marketing point of view, electricity is a product and the power quality is the index of the product quality [9].The prime objective of utility companies is to provide their consumers an uninterrupted sinusoidal voltage of constant amplitude. Unfortunately, this is becoming increasingly difficult to do so, because the size and number of non-linear and poor power-factor loads such as adjustable speed drives, computers, power supplies, programmable logic controllers, furnaces, power converters, induction motors and traction drives are finding its applications at domestic and industrial levels. These nonlinear loads draw non-linear current and degrade electric power quality. The quality degradation leads to low power-factor, low efficiency, and overheating of transformers [5].The objective of this paper is to mitigate power quality problems at MPM. In order to achieve the objective the following are the specific objectives:

(i) To study the impacts of voltage sags and swells to MPM.
(ii) To apply Unified Power Quality Conditioner (UPQC) at MPM to maintain the load voltage to nominal value or desired magnitude.

II LITERATURE REVIEW

Power quality is defined as the degree to which the supply system is free from major distortions and fluctuations in supply voltage and frequency, and free from interruptions to supply. There are two classes of power quality problems: phenomena due to low quality of current drawn by the load caused by nonlinear loads and voltage disturbances that are caused by faults in the power system [11].The increase of nonlinear and sensitive loads in the distribution system causes noticeable current deviations that lead to power quality disturbances; therefore, power quality problems are no longer considered as only voltage quality problems. Power quality becomes important with the introduction of sophisticated devices, whose performance are very sensitive to the quality of power supply. Modern industrial processes are based on a large amount of electronic devices such as programmable logic controllers and adjustable speed drives. The electronic devices are very sensitive to disturbances[6].Thus industrial loads become less tolerant to power quality problems such as voltage sags, voltage swells, voltage flicker/imbalance, negative sequence current, reactive power, transients, frequency variation and harmonics[8]

A. *Effect on Variable Speed Drives*

Variable speed drives (VSD) use an electronic converter to produce a variable frequency motor drive voltage from the fixed supply frequency. They are used extensively in industrial processing, materials handling and building management. During sag, the amount of energy supplied by the electrical system is reduced and may be below that required by the process, resulting in loss of control. Since motor controlled processes rarely operate in isolation, this can result in loss of synchronization with other parts of the process and uncoordinated shut down. The problems of voltage sags applied to variable speed drives are:

- It is not possible to supply sufficient voltage to the motor (loss of torque, slowdown);
- The control circuits supplied directly by the network cannot function;
- There is overcurrent when voltage recovers (the drive filter capacitor is recharged);
- There is overcurrent and unbalanced current in the event of voltage sags on a single phase;
- There is loss of control of DC drives functioning as inverters (regenerative braking).

B. Effects on AC Contactors, Relays and Circuit Breakers

Contactors, relays and circuit breakers are made for all operation in a different range of coil voltage and contact ratings. Nowadays, most of the places, the contactor function has been replaced by power-electronics devices such as GTOs and IGBTs. Control relay functions have been replaced by PLCs using digital logic. Whether electromagnetic or solid state, the devices are impacted by line-voltage sags and Interruptions [2].

C. Effect on Personal Computers

The malfunction of Personal Computers (PCs) incorporated in a real-time system because of voltage disturbances effect more badly than the malfunction of the PC used offline. The modes of personal computer malfunction under line voltage sag occur as in DC filter capacitor voltage of the power supply doesn’t go with time. The software problems create the problems that include; Lockup, interruption, (blue screen), No response to any command from the keyboard and Blocking of the operating system. Automatic restarting of the system, or a permanent black screen, making a manual restart necessary, can identify hardware misoperation [2].

D. Product Damage

Sometimes PQ problems in manufacturing processes can result in product damage. Occasionally, the damage can be directly observed and the damaged product discarded or recycled. Product damage can be costly if the damage is delicate and the effects take some time to surface. Service or product losses due to a power disturbance need to be known in quantifying PQ costs .The number of units of service or product losses and the cost per unit of service or product loss/repair are key elements in determining the total cost of a power disturbance.

E. Decreased Equipment Life

Many systems that experience disturbances, both detected and undetected, have resulted in decreased equipment life. High-energy, fast-rise-time transients can cause outright circuit board failure, even for systems protected by transient suppressors, or can cause degradation over time such that burnout is only delayed. Harmonic distortion and phase unbalance can combine to overstress motors and transformers, shortening their useful lifetimes, and consequently increasing production costs. Hence, equipment lifetime affected by PQ disturbances can show up as direct and hidden costs.

F. Unified Power Quality Conditioner

It is a combination of a shunt (DSTATCOM) and a series compensator (DVR) connected together via a common DC link capacitor. The series active power filter (APF) cancels voltage-based distortions, while the shunt APF eliminates current-based distortions [6]. UPQC is a versatile device that can compensate almost all power quality problems such as voltage harmonics, voltage unbalance, voltage flickers, voltage sags and swells, current harmonics, current unbalance, and reactive current. The overall performance of the right-shunt UPQC (DSTATCOM) is better than the left-shunt UPQC (DVR). Fig.1 shows the right-shunt UPQC.

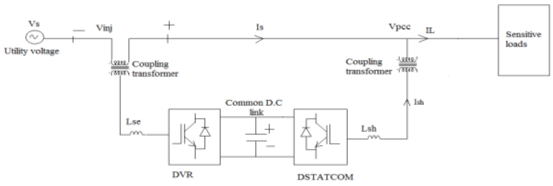

Fig.1: Schematic Circuit of UPQC

III. METHODOLOGY

Among all power quality disturbances voltage sag and swell are crucial problems in sensitive loads such as programmable logic controllers, computers and adjustable speed drives. These disturbances affect both utility (TANESCO) and customers (MPM). The methodology adopted in the study is the location of the study area, data collection and other necessary information from the field and measurement of voltage sag and swell using power quality recording instruments.

A. Area of Study

The study was conducted at Mufindi Paper Mills Limited in Iringa region. This area was selected because several breakdowns were reported due to voltage variation. During data collection, the researcher was involved in performing the following activities:

- Record of monthly downtime hours, monthly paper production in tonnes, rejects of paper in tonnes, records of damaged equipment and power factor of the Mills;
- Industry operational pattern information, such as, average number of operating hours per day and average number of operating days per year;
- Measurements of voltage sag and swell using Power quality Recorder (PQR) instrument.

B. Measurement of Voltage Sag and Swell

Power quality recorder (PQR) instrument is the combination of Impedograph, Vectograph and Provograph. They are stand-alone recorders. They are permanent connected to a power network, and left alone to record power quality unattended for weeks, months and years at a time. Recordings are stored in internal non-volatile memory. Supply interruptions will stop recording, but no recordings are lost and recording continues as soon a supply is restored. The recorders have no user interfaces, such as screens and keyboards, since they are used in an unattended manner. Instead, the recorder interacts with its operator by means of a personal computer (PC). The included software applications allow the operator to configure the recorder, retrieve stored recordings from it and it helps with the analysis of PQ recordings, all via a PC.

C. Data Analysis

During the study, the essential data were collected. Thereafter editing, classifying according to the requirement of each specific objective, tabulating and computing was done to facilitate interpretation and analysis. The analysis intended to accomplish the research objectives. The simulation results using MATLAB/SIMULINK of the proposed circuit are presented to verify the ability of UPQC in the voltage sag and swell mitigation.

IV. DATA PRESENTATION, ANALYSIS AND DISSCUSSION OF THE RESULTS

A. Impacts of Voltage Sags and Swells to Mufindi Paper Mills

Reliability of supply and power quality is two most important facets of any power delivery system today [10]. Voltage swells are not as important as voltage sags because they are less common in distribution systems. Programmable Logic Controllers (PLC) used to control the speed of DC motors at MPM are very sensitive to voltage sags and swells. Since motor controlled processes rarely operate in isolation, voltage sags and swells result in loss of synchronization with other parts of the process, uncoordinated shut down as well as creating a large current unbalance that could blow fuses or trip breakers. Other impacts includes failure to meet the target of paper production as set by the MPM management basing on the capacity of the paper machine, poor quality of paper (rejects), equipment damage and energy wasted due to restart of the process.

B. Unplanned Downtime

When equipment is not operating due to unscheduled downtime, productivity drops and process consistency suffers or fails, which in turn leads to product waste. The losses include the cost of idle labour starting from the moment of interruption and ending when normal process activity resumes, and process restart cost. Downtime hours at Mufindi Paper Mills for the indicated years are as in Table 1

Table 1: Monthly Unplanned Downtime Hours

MONTHS	2014		2015		2016	
	HRS	NO.OF EVENTS	HRS	NO.OF EVENTS	HRS	NO. OF EVENTS
Jan.	11.3	6	11.08	5	10.03	7
Feb.	10.5	4	12.7	6	10.9	5
March	8.6	5	9.4	5	12.5	6
April	6.4	3	6.2	4	8.5	5
May	6.3	4	6.4	2	8.2	3
June	5.75	2	7.3	3	7.5	4
July	6.6	3	6.5	4	5.05	3
Aug.	5.1	2	4.03	3	6.4	4
Sept.	5.17	4	6.4	4	4.5	2
Oct.	6.9	3	5.1	4	4.2	3
Nov.	7.4	4	7.5	3	8.8	4
Dec.	9.5	5	7.9	5	9	5
Total Hours	**89.5**	**45**	**75.5**	**48**	**93.8**	**50**

Source: Mufindi Paper Mills

When a process is interrupted, other auxiliary processes, such as heating, cooling, ventilation and filtration, may also trip. These processes must be re-established and verified before the main process can restart, requiring additional time and labour. The process restart of paper machine when tripped needs 30 minutes (half an hour) to reheat the machine before resuming production. During process restart, energy in kWh is wasted. The total load of paper machine is 2,880 kW. During restart process the machine run under no load, thus its power is 490 kW. From Table 1 the total energy wasted for three years under study is $(45 + 48 + 50) \times 0.5hr \times 490kW = 35{,}035kWh.$

The cost of 1 kWh is 163 TZS for MPM which is categorized under high voltage maximum demand usage tariff (T3). The loss incurred by MPM due to wasted energy is $\frac{163TZS}{kWh} \times 35{,}035kWh = 5{,}710{,}705TZS.$

This amount is converted to USD at an exchange rate of 2200TZS per USD, gives a total loss due to wasted energy of USD 2,596. From Fig. 2 the number of voltage sags/swells events increases for the months of November, December, January, February, and March due to thunderstorms and lightning strikes that cause a significant number of voltage sags which leads to process downtime.

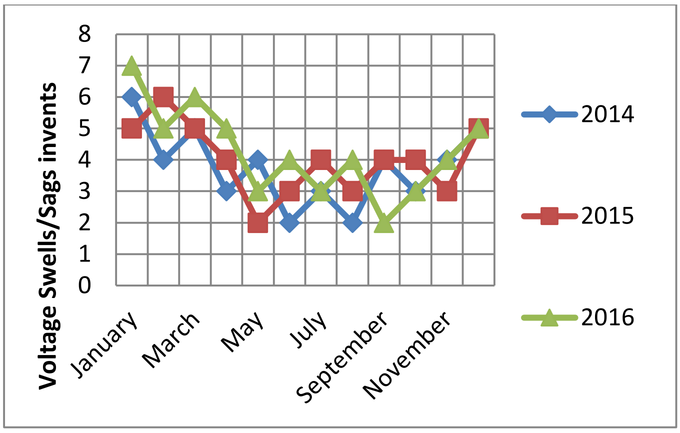

Fig. 2: Voltage Sags and Swells Events

C. Equipment Damage

When a process is interrupted the shutdown occurs in a disorderly manner as a result some of the equipment could be damaged. Damage may be instantaneous (e.g. damage by mechanical collision) or incremental (e.g. by overheating due to loss of coolant) leading to shorter equipment life, increased maintenance, and damage of electronics components. Equipment damage cost consists of cost of purchasing new equipment in case of the damage being beyond repair, cost of installation of new equipment and parts, and cost of repair, adjustment and calibration of damaged equipment. Table 2 indicates the list of equipment damaged due to voltage sags and swells.

Table 2: Losses Incurred by MPM Due to Equipment Damage for 2016

S/NO	EQUIPMENT	SPECIFICATION	QUANTITY	VALUE IN USD
1	PLC	Three phase 415V,50HZ,150kVA	4pcs	14,000
2	Stabilizers	Three phase 415V,50HZ,300kVA	2pcs	20,000
3	UPS	Three phase 415V,50Hz,250kVA	3pcs	7,500
4	Computers	AMD, Fx 8-coreprocessor,4GHz	5pcs	6,000
			Total losses	47,500

Source: Mufindi Paper Mills Annual Report of 2016.

The survey made in this study at MPM recognized an average equipment damage of USD 47,500 per year. For three years under study, the total loss due to equipment damage is USD 142,500.

D. Power Disturbances in Distribution System to Mufindi Paper Mills

Power quality monitoring on the system network was done based on methods described in part **B** and these power quality disturbances data captured by PQR instruments are used as indication and justification of the study problem. Voltage sags and swells are detected by their symptoms such as lights flickering, excessive equipment heating, and malfunctions of computers, programmable logic controllers and stoppage of motors.

Voltage sags and swells give severe impacts to the industrial customer's equipment. Truly severe swells may stress components to the point of failure, but other than that there is seldom disruption or damage [3].The severe power quality disturbances that cause stoppage of paper machine was voltage sag as seemed to occur most frequently as compared to other power quality disturbances. Therefore, voltage sag is one of the prime factors due to which MPM suffers huge loss because of downtime, rejects, idle workers and equipment damage.

E. The UPQC Model

UPQC is one of the major custom power solutions, which is capable of mitigating the effect of supply voltage sags and swells at the load end or at the point of common coupling (PCC) in distribution system. The performance of the designed UPQC is evaluated by using the MATLAB /SIMULINK program. Fig. 3 indicates the proposed UPQC and its control schemes, which are built with the standard blocks available in the Sim-power system toolbox of the MATLAB /SIMULINK. The rating of the UPQC is decided by considering the installed capacity, the sag level, and the duration of the fault. The rating of UPQC depends upon the rating of series and shunt compensators. In this research, the rating of UPQC is 5,700kVA, which is the installed capacity of MPM. The UPQC model is the combination of Shunt and Series models.

F. The Shunt Compensator Model

The Shunt compensator is controlled to maintain DC link voltage at a constant value. The converter is modeled as a current controlled voltage source [4].

The measured values of different currents and voltages are converted to direct and quadrature axis components taking PCC bus voltage as reference. The direct current component of Shunt compensator is controlled to maintain DC link voltage at a constant value. The quadrature current component is responsible for reactive power control at PCC. The PI block in DC link controller provides necessary direct reference current based on the difference in measured and set value of DC link voltage.

G. The Series Compensator Model

The Series compensator is controlled to maintain the load bus voltage at a predetermined value. The series inverter is controlled in such a way that it injects voltages ($Vinj_a$, $Vinj_b$ and $Vinj_c$), which cancel outs the distortions present in the supply voltages (V_{sa}, V_{sb} and V_{sc}), thus making the voltages at PCC ($V_{la,}V_{lb}$ and V_{lc}) perfectly sinusoidal with the desired amplitude. Thus, the sum of supply voltage and the injected series filter voltage makes the desired voltage at the load terminals. Since, the supply voltage is distorted, a phase locked loop (PLL) is used to achieve synchronization with the supply voltage [12].

Table 3: UPQC system parameters

S/NO.	Parameters	Value
1	Supply Voltage	415V
2	Supply Frequency	50Hz
3	Ac load inductance	2mH
4	Dc load inductance	10mH
5	Dc load resistor	30 Ω
6	Dc link Voltage	700V
7	Link capacitor	1100µF
8	Shunt inductance	3.5mH
9	Shunt filter Resistor	5 Ω
10	Shunt filter Capacitor	10 µF
11	Switching Frequency	15kHz
12	Series inductance	1.5mH
13	Filter Resistor	5 Ω
14	Filter Capacitor	20 µF
15	Switching Frequency	12kHz
16	Series Transformer turns ratio	1:1

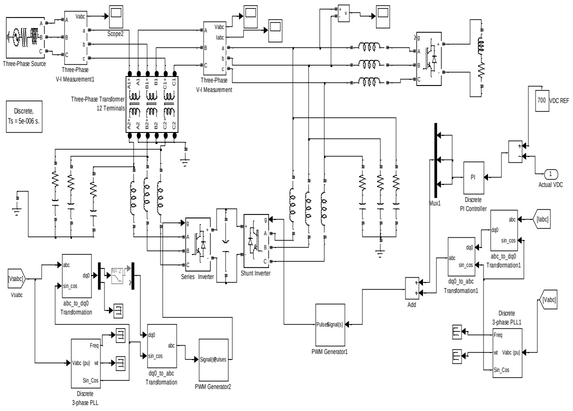

Fig. 3: Simulation Model of UPQC

H. Simulation Results and Discussion

In order to validate the control strategies simulation studies were made as in the system described in Figure 3.The power quality capability of the UPQC system is tested through MATLAB. The simulation results for the proposed three-phase three wire system utilizing UPQC are shown in Fig. 4 to 9 by considering voltage sags and voltage swells respectively.

I. During Voltage Sags

From simulation, the sag voltage started at $t_1 = 0.16\, sec.$, with voltage 60 % sagging and lasted at $t_2 = 0.24\, sec,$ with total voltage sag duration of 0.08 sec, as shown in Fig. 4. During the voltage sag condition, the series compensator of UPQC is providing the required power of the load by injecting in phase compensating voltage (60 %) equals to the difference between the reference load voltage and source voltage, as shown in the fig. 5. Compensating voltage is injected only during occurrence of sag. The load voltage profile shown in the Figure 6, shows that UPQC is maintaining it at desired constant level even during the sag on the system such that load bus is free from the sag voltage variation. While the series compensator is providing the required real power to the load, the shunt compensator of UPQC is maintaining the DC link voltage at constant level such that the series compensator can provide the needed real power to the load.

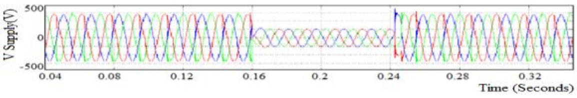

Fig.4: Simulation results during voltage Sag

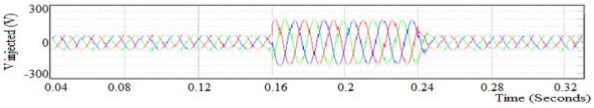

Fig.5: Voltage Injected by Series Compensator

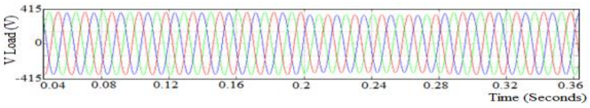

Fig. 6: Compensated Load Voltages

J. During Voltage Swells

The simulation started with the supply voltage swell is generated as shown in Fig. 7. In this simulation, the voltage swell (25 %) occurred during the period of 0.12 sec to 0.2 sec as shown in Figure 8. Under this condition the series Compensator is absorbing the extra real power from the source by injecting an out of phase compensating voltage (25 %) in the line through series transformers, as shown in the Fig.8. the series compensator of UPQC reacts quickly to inject the negative voltage magnitude to correct the supply voltage. The injected voltage is produced by series compensator in order to correct the load voltages. The load voltage profile in the Fig.9 shows the UPQC is effectively maintaining the load bus voltage at desired constant level.

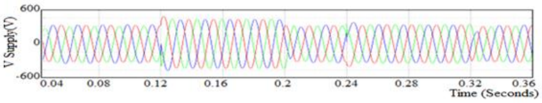

Fig.7: Simulation Results During Voltage Swell

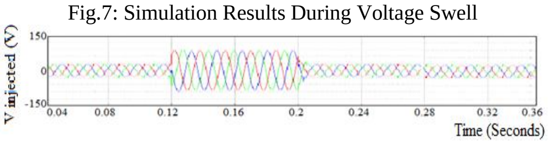

Fig.8: Negative Voltage Injected by Series Compensator

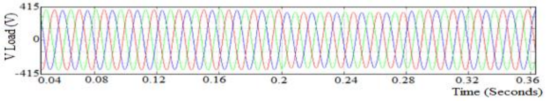

Fig. 9: Compensated Load Voltages

V. CONCLUSIONS

The proposed control scheme for UPQC has been validated through simulation results using MATLAB software along with SIMULINK and sim-power system toolbox. The performance of the UPQC has been observed to be satisfactory for power quality improvements like mitigation of voltage sag and voltage swell as shown in the simulation results. The proposed UPQC was designed, modeled and simulated through synchronous reference frame theory. PI controller balances the power between series and shunt inverters by stabilizing DC link voltage because the injected voltage depends on the regulated voltage of DC link capacitor. The series compensator provides protection of adjustable speed drive from voltage disturbances coming from the network. The shunt compensator helps series compensator during voltage sag and swell condition by maintaining the DC link voltage at set constant level. Simulation results show that UPQC mitigates voltage sags/swells, and does better load regulation and balancing for dynamic loads than uninterrupted power supply (UPS) installed at MPM and can tolerate long duration fault conditions effectively. Thus, it gives enhanced performance when compared to DSTATCOM and DVR. Results show that it gives good steady state and transient performance. The proposed control scheme is feasible and simple to implement all of which verifies the effectiveness of applying such a flexible control strategy in UPQC.

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LIST OF ABBRIVIATIONS AND ACRONYMS

APF	Active Power Filter
ASD	Adjustable Speed Drives
DSTATCOM	Distribution Static Compensator
DVR	Dynamic Voltage Restorer
MPM	Mufindi Paper Mills
PC	Personal Computer
PI	Proportional Integral
PQ	Power Quality
PQR	Power Quality Recorder
TANESCO	Tanzania Electric Supply Company
TZS	Tanzanian Shillings
UPQC	Unified Power Quality Conditioner
UPS	Uninterrupted Power Supply
USD	United State Dollar
VSD	Variable Speed Drives

REFERENCES

[1] M.H.J. Bollen, “Understanding Power Quality Problems, Voltage Sags and Interruptions,” New York: IEEE Press, 2000.

[2] S. Djokic, G. Vanalme, J. V.Milanovic, and K. Stockman, “Sensitivity of Personal Computers to Voltage Sags and Short Interruptions,” IEEE Transactions on Power Delivery, vol. 20, no. 1, pp. 375– 383, 2005.

[3] R.C. Dugan, M. McGranghan, and W. Beaty, “Electrical power systems Quality,” New York, McGraw-Hill, 1996.

[4] P. Giroux, G. Sybille, and H. Le-Huy, Modeling and simulation of a Distributed STATCOM using Simulink’s Power system blockset. The 27th Annual Conference of the IEEE Industrial electronics, IECON’01, vol. 2, 29, pp. 990-994, 2001.

[5] E.W. Gunther, and H. A Mehta, Survey of distribution system power quality, IEEE Trans. On power Delivery, vol.10, No.1, pp.322-329, 1995

[6] H. Hingorani, “Introducing Custom Power” IEEE Spectrum, vol.32, no.6 p 41-48, 1995.

[7] Y. Pal, A. Swarup, B. A. Singh, Control strategy based on UTT and I CosΦ theory of three-phase, four wire UPQC for power quality improvement, International Journal of Engineering, Science and Technology, Vol.3, no.1, pp.30-40, 2011.

[8] M. Rashid, Power Electronics: Circuits, Devices, and Applications, third Edition, Prentice Hall New Jersey, USA, 2004.

[9] P.J Rens, and P.H. Swart, “On techniques for the localization of Multiple distortion sources in three-phase networks:Time-domain verification,” ETEP, vol. 11, no. 5, pp. 317–322, 2001.

[10] C. Sankaran, Power quality, Boca Raton, Fla.:CRC Press LCC, 2002.

[11] A. Sannino, J. Svensson, and T. Larsson, Power electronic solutions to power quality problems. Electric Power Systems Research, 66(1): pp. 71-82, 2003.

[12] B.N. Singh, and A. Venkateswarlu, A Simplified Control Algorithm for Three-Phase Four-Wire Unified Power Quality Conditioner, Journal of Power Electronics. vol.10, no. 1, pp.91-96, 2010