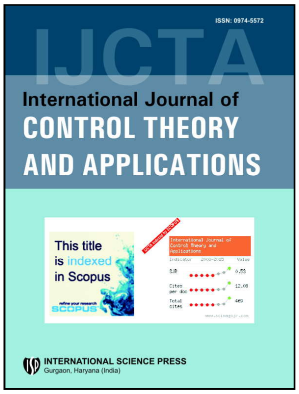

International Journal of Control Theory and Applications

ISSN : 0974-5572

Volume 10 • Number 6 • 2017

Fuzzy Controller for Automatic Tap Changing in Transformers for Power Quality Enhancement in a Smart Grid Distribution System

K. Sujatha[1], R.S. Ponmagal[2], K. Senthil Kumar[3] and K.S. Ramkumar[4]

[1] *Professor, Dept. of EEE, Center for electronics Automation and Industrial Research (CEAIR), Dr. MGR Educational and Research Institute, Chennai, India, Email:* drksujatha23@gmail.com
[2] *Professor, Dept. of CSE, Dr.MGR Educational and Research Institute, Chennai, India.*
[3] *Professor, Dept. of ECE, Dr.MGR Educational and Research Institute, Chennai, India*
[4] *I yr., Dept. of ECE, J.N.N Institute of Engineering, Chennai, India.*

Abstract: A smart grid is an evolved grid system that manages electricity demand in a sustainable, reliable and economic manner, built on advanced infrastructure and tuned to facilitate the integration of all involved. The smart grid is the future for electrical systems. Smart metering circuit consists of power transducers such as AC voltage, AC current, frequency etc. The transducers converts its respective inputs into DC voltage output and fed to analog to digital convertor which converts into digital signals and fed to smart grid system computer. The automatic tap changing is done using fuzzy controller. Smart grid computer is fed with information of the individual consumer prepaid amount. The information of this prepaid amount is fed to the respective smart metering circuit and stored. The consumer is allowed to consume power till the recharged amount available and it is interrupted with an automatic isolation circuit until the consumer usage exceeds their prepaid amount.

Keywords: Smart grid; tap changing; Transformers; Power Quality and fuzzy controller

1. INTRODUCTION

A smart grid is an evolved grid system that manages electricity demand in a sustainable, reliable and economic manner, built on advanced infrastructure and tuned to facilitate the integration of all involved. The smart grid is the future for electrical systems, as it is designed to meet the four major electricity requirements of our global society: capacity, reliability, efficiency, quality and sustainability.

Today, existing grids are under pressure to deliver the growing demand for power, as well as provide a stable and sustainable supply of electricity. These complex challenges are driving the evolution of smart grid technologies Smart grids will make use of new design concepts and advanced materials in system components like transformers and circuit breakers to improve efficiency, safety and operational performance. Widespread use of power electronic devices will help maximize performance of existing assets and make the grid more resilient in the event of disruptions.

Energy storage technologies will help mitigate demand peaks and allow the grid to integrate more renewable energy power sources. More flexible transmission and distribution systems can accommodate fluctuations in supply, increase efficiency and optimize system operations. Powerful monitoring and control system will help prevent disruptions before they occur. A smart grid combines all of these features, linked by communication technologies. The future electrical system must be able to meet demand for electricity in a way that also satisfies environmental concerns. In the future, power systems will have to adapt to new types of consumer demand, such as the need to power electric vehicles.

The most advanced smart grid technologies are in electrical transmission, and ABB is the market and technology leader in many of them: Flexible Alternating Current Transmission Systems (FACTS) devices enable existing transmission lines to deliver maximum power, and help stabilize the grid with precise power control. High-Voltage Direct Current (HVDC) technology can deliver long-distance power with low losses on land and under water, and connect asynchronous grids. Wide Area Monitoring Systems (WAMS) track critical system parameters to prevent development of dangerous instability in the network. Supervisory Control and Data Acquisition Systems (SCADA) analyze real-time grid conditions, providing data for fast power adjustments. The biggest changes are in the distribution network and for end users, especially commercial and residential users. Innovative technologies for smart distribution networks and buildings include smart meters, building automation systems, electric vehicle charging equipment, low-voltage solar inverters, high-efficiency distribution transformers, and substation and feeder automation sending messages peer-to-peer to a base station. This is made possible using cloud technology. Cloud computing is a style of computing in which dynamically scalable and often virtualized resources are provided as a serve over the Internet. Users need not have knowledge of, expertise in, or control over the technology infrastructure in the "cloud" that supports them. They serve as virtual servers and on demand 'add and subtract processors, memory, network bandwidth and storage for real-time processing of heterogeneous data sources in order to make critical decisions. To increase the robustness of the system fuzzy controllers [2] are used. They are needed to offer problem specific heuristic control knowledge for the Inference Engine Design which occurs due to imprecision and uncertainty of the Sensor readings. It also requires low computation time which favours the battle ground situations.

2. A SURVEY ON EXISTING VS PROPOSED TECHNOLOGY

Creation of a Smart Grid provides utilities and their customers a significant improvement in power reliability and services. To date, Smart Grid has attracted various researchers from different perspectives. This paper presents a review of Smart Grid technologies and its characteristics. An extensive literature review is introduced. One can see variety of problems and challenges in the field of Smart Grid. Hence, this paper can provide a help to find a new research point in this field [3].

Many different technologies have been growing under the umbrella of Smart Grids, which can be split into three major blocks: generation, transmission, and distribution. Generation and transmission have been evolving and improving as they have been under the control of utility companies, but distribution has been lagging behind on some of these improvements, due to the number of stakeholders involved in the process. With the integration of information and communication technology into the electricity distribution, there has been a spike in research and other studies to prepare for the future [4,5].

Under normal circumstances, power transformers are designed to predominantly operate within the linear portion of the transformer core magnetization curve. The basic goal of this design is to retain a reasonable amount of linearity and to stay below flux density values that would incur excessive losses. In recent years, however, we are facing more challenges of saturation, such as the half-cycle saturation problem caused by geo-magnetically induced currents (GIC) and over flux issues in quadrature boosters (QB). In deep saturation, hot spots may be observed, which can damage the adjacent insulations and even lead to transformer failure. Therefore, it is vital that understand the performance of electrical steels in deep saturation well to take up those challenges.

Unfortunately, there has been far too little knowledge about it from experiments. This paper conducts a literature survey on electrical steels as well as power transformer cores, followed by a discussion about the current series of standards for measuring the magnetic properties of electrical steels. The knowledge gap in deep saturation measurement is highlighted, and corresponding solutions are proposed [6,7].

The paper describes a condition monitoring and diagnostic monitoring system developed for power transformer on load tap changers (OLTCs). The system has been installed in distribution substations to continuously monitor the operation of OLTCs on 33/11 kV power transformers. The field trials have demonstrated that the system can provide reliable indication regarding the actual condition of OLTC contacts. Also presented in the paper are the details about an industry survey on failure modes of commonly used OLTCs in Queensland electricity transmission and supply industries [8, 9].

Voltage regulation by means of coordinated voltage control is one of the challenging aspects of distribution system operation. Integration of distributed generation (DG), which can also be operated in voltage control mode, in distribution systems may introduce adverse effects including control interactions, operational conflicts and long term oscillations. The seamless operation of distribution systems embedded with DG for effective voltage control is one of the challenging tasks, mainly because (a) DG may interact with the conventional voltage control devices and (b) prioritised operation of different voltage control devices depends on the network topology and real-time characteristics of the system. Coordinated operation involving multiple voltage control devices (i.e., on-load tap changers and voltage regulators in addition to local capacitor banks) [10,11].

Local controllers are essential in distribution networks; they are employed in classical devices such as load tap-changing (LTC) transformers and switchable shunt capacitors, and more recently in distributed generation (DG). The effective use of distribution management system (DMS) applications requires an accurate model of the interaction between the local controllers through the distribution system. This paper presents a new sensitivity matrix approach for modeling such interactions, and demonstrates its application in the implicit Z-Bus Gauss method for power flow computation [12, 13].

3. MOTIVATION OF THE WORK

To maintain the voltage throughout the day, the variation of load is the main criteria. It is more in the peak hours, medium in the rest of the hours and less in the midnight to early morning. This variation is due to the industrial and residential load patterns. In this project it is achieved to maintain the quality of power throughout the day by operating the transformers with multiple taps. An automatic changeover circuits are provided to change the taps and to deliver the voltage at the consumer end within the desirable ranges.

4. EXISTING SYSTEM

In our current system, the high–voltage transmission grid is a sophisticated, highly controlled network that supplies electricity to distributed networks, which can be viewed simply as wires delivering electricity to users. The transmission grid must meet all demands of the distributed systems. The electrical grids are generally used to carry power from a few central generators to a large number of users or customers and do not allow for real time information to be relayed from the grid. Some of the significant issues include

The current electricity delivery uses a Supervisory Control and Data Acquisition System (SCADA) which suffers limited bandwidths and relatively low data transmission rates that often requires several seconds or more to respond to an alarm or system change and there is no visibility in the distribution network below the sub-station [1].

Electricity demands vary all the time, and the cost to meet these demand changes as well. For the existing grid, supply has to change according to the demands continuously and the power grid will also need to maintain a buffer of excess supply, which results in lower efficiency, higher emissions, and higher costs [2].

Transformer used in the present system is available with multiple taps for the best application. These taps are rarely used in distribution system and frequently used in high voltage transmission in substation level with concurrence from source station. In this project, it is achieved to maintain the quality of power throughout the day by operating the transformers with multiple taps.

5. PROPOSED SYSTEM

In order to improve the voltage at the consumer end, the voltage drop across the transformer (step up transformer with multiple tap outputs) should not fall below the specified level. The transformer which is to be included in the project is provided with five taps (normal, boost and advance tap in first stage and super boost & super advance boost levels) to regulate the voltage level. Computer receives the distribution voltage through the voltage transducer and ADC activates suitable taps to maintain the desired voltage levels. Transformer temperature is also monitored and alarms are generated in case of abnormal temperature in the transformer windings.

6. RESULTS AND DISCUSSION

A tap changer is a connection point selection mechanism along a power transformer winding that allows a variable number of turns to be selected in discrete steps. A transformer with a variable turns ratio is produced, enabling stepped voltage regulation of the output.

For controlling of a nonlinear process a conventional controller is not enough to obtain a desired performance. To ensure good performances and stability for all the operation set point in nonlinear process, the controller gains should change to adopt the variation of physical parameters. Fuzzy controller is used for such processes, but there is a significant need to develop methods for the automatic tuning of controllers for nonlinear systems. Hence fuzzy inference system to tune the controller settings for improving the system performance is incorporated here. This provides a nonlinear mapping from the error signal e (t) and change in error ce(t), to the controller gain parameters Kp , Ki , and Kd [8]. The tap selection is made automatic using Fuzzy Logic Controller (FLC).

The voltage of 230 volts (nominally) is used. So we have considered the upper and lower limits as 240V and 220V respectively. The choice of the voltage in this range, gives different current values. If the voltage received from the source is below 220V, it is called as under-voltage. If the voltage received from the source is above 240V, it is called as over-voltage. Using these criteria, we have calculated the power output for each of load conditions. The required parameters to calculate power are voltage and current. Also, to vary the voltage drop across load, we can vary the number of taps. This tap selection may be made via an automatic tap changer mechanism and controller.

Here 5 examples are taken to demonstrate how the output of the power increases using taps. The stage remains 1 up till the use of 2 taps. If the number of taps used is 3 or more than 3, then the Stage gets upgraded by 1. That is the stage becomes 2. In each of the stage, the load is increased by 40W to observe the changes in power output.

Table 1
Fuzzy Rules for Computation

e(k) / ce(k)	*N*	*ZE*	*P*
N	B	M	S
ZE	M	S	M
P	S	M	B

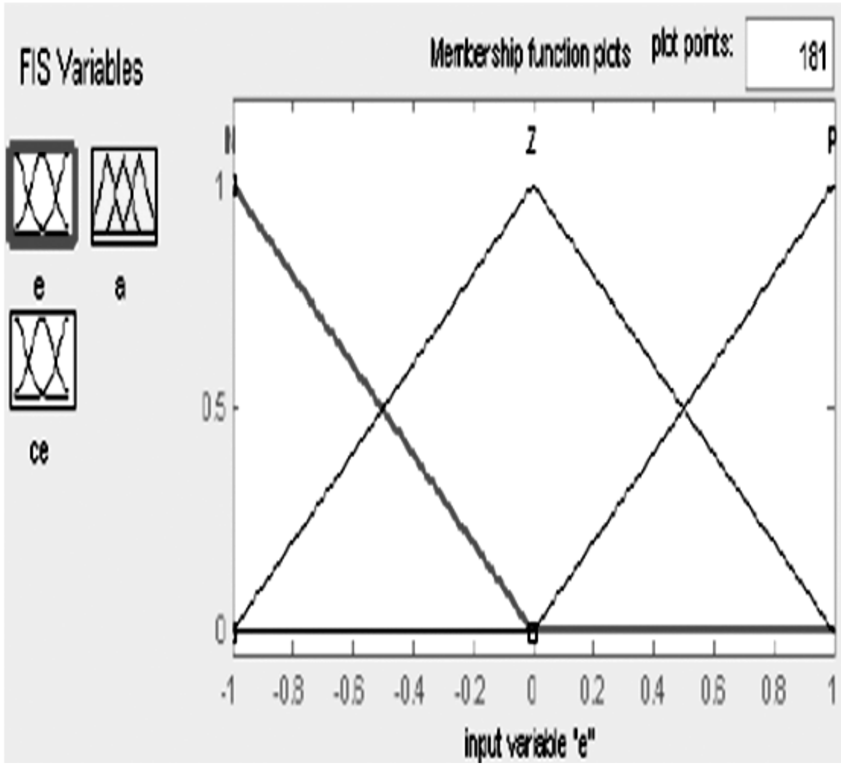

Figure 1: Membership functions for the input 'e' error

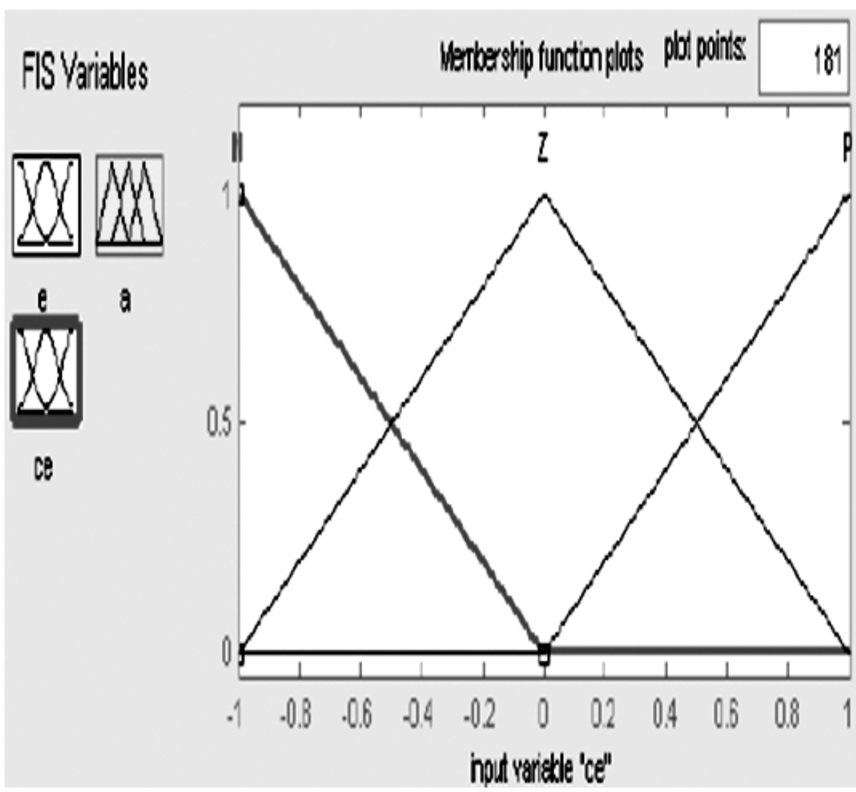

Figure 2: Membership functions for 'ce' change in error

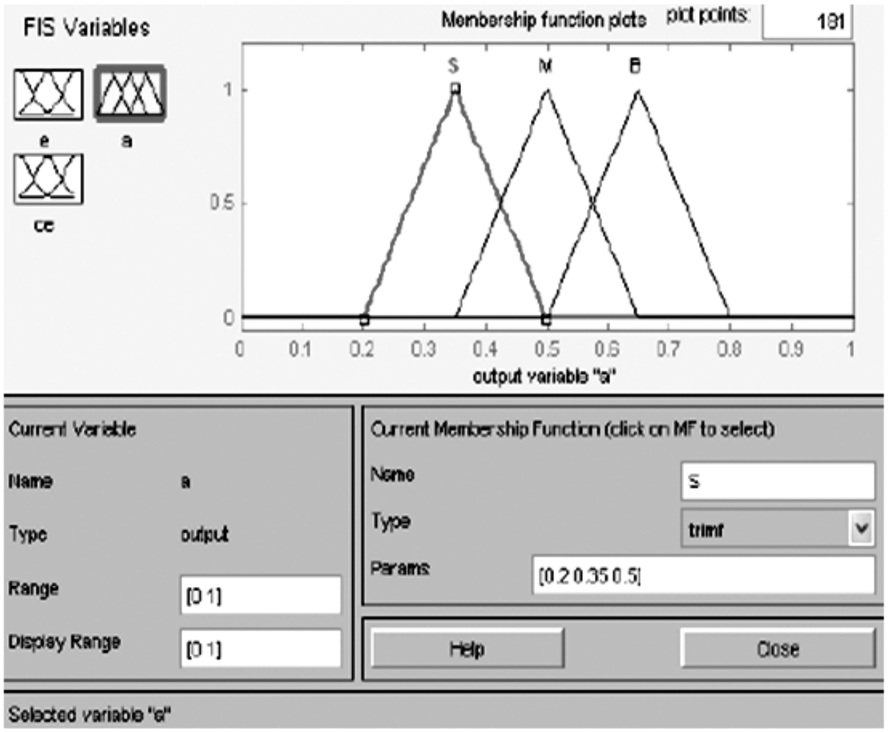

Figure 3: Membership functions for the manipulated variable m(t)

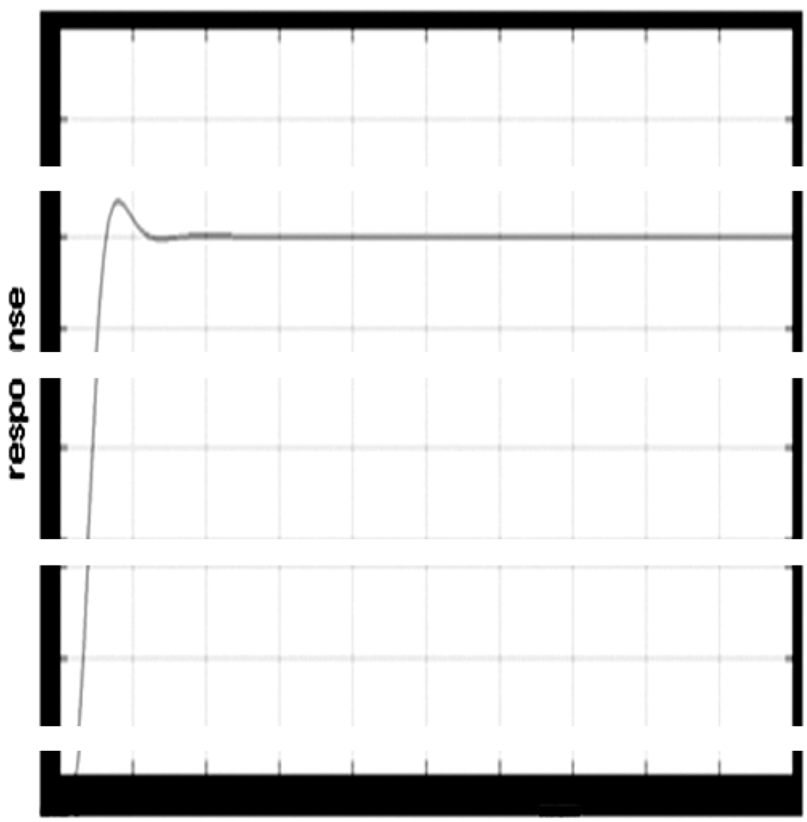

Figure 4: Response for the Automatic tap changing system using FLC

Time in secs

Table 2
Rules for fuzzy inference system

Controller gain				*e(t)*		
Δe(t)	VB	NB	NS	ZE	PS	PB
	NB	VB	VB	VB	VB	VB
	NS	B	B	B	MB	VB
	ZE	ZE	ZE	ZE	S	S
	PS	B	B	B	MB	VB
	PB	VB	VB	VB	VB	B

The Figure 1, 2 and 3 denotes assignment of triangular membership function for the input variables, error ‘e(t)’, change in error ‘ce(t)’ and the manipulated variable m(t) respectively. Table 1 and 2 shows the fuzzy rules and fuzzy inference system. Figure 4 shows the response for the automatic tap changing using FLC.

6.1. Tap Changing under No load condition

The above picture in Figure 5 shows the power output at no load condition. Since there is no load, there is no need of taps. Because of which the optimum voltage drop across the system remains constant. The voltage from the source is 223V. For which the corresponding current is 0.0A. Thus, the power output comes to be 0W/0VA as indicated in Table 3.

6.2. Tap Changing under Rated load condition

The above picture in Figure 6 shows the power output at the load condition of 40W. Since there is some load, taps need to be changed to maximize the power at output. Because of load, the voltage across the system reduces. So to maximize the power, a tap is needed. The voltage from the source is 228V. For which the corresponding current is 0.3A. Thus, the power output comes to be 69.8W/69.8VA as indicated in Table 4.

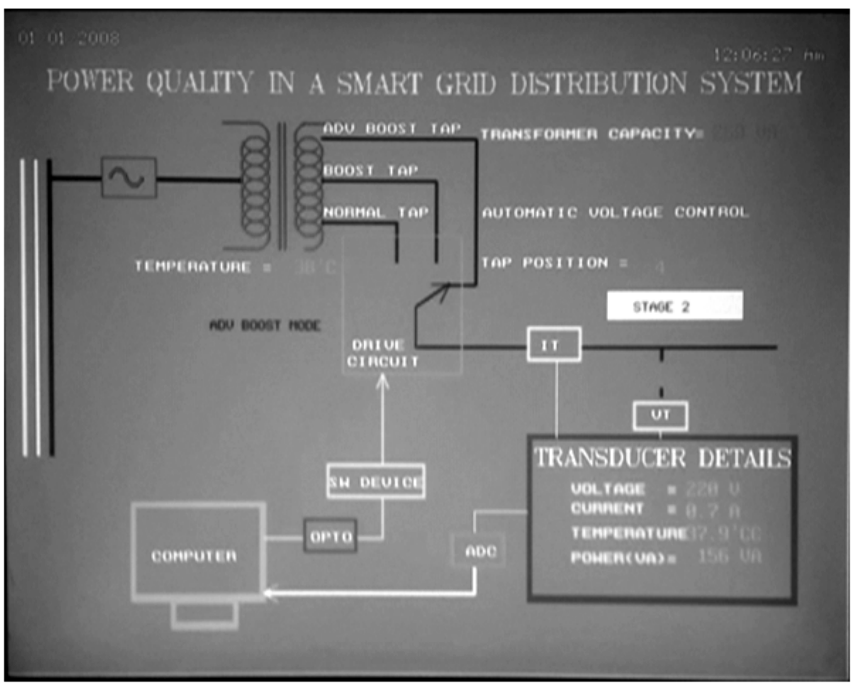

Figure 5: Power output corresponding to no load condition

Table 3
Readings related to no load condition

Load Conditions	*No Load*
Stage	1
Number of Taps	0
Voltage	223V
Current	0.0A
Power	0VA

6.3. Tap Changing under Rated load of 232 V condition

Now, the load has been increased by 40W. Thus, the Figure 7 shows the power output at the load condition of 80W. Since there is some load, taps are to be changed to maximize the power at output. Because of load, the voltage across the system reduces. So to maximize the power at output, we need taps. Here 2 taps are used. The voltage from the source is 232V. For which the corresponding current is 0.7A. Thus, the power output comes to be 163.5W/163.5VA as indicated in Table 5.

6.4. Tap Changing under Rated load of 237 V condition

Now, the load has been increased by 40W. Thus, the above picture in Figure 8 shows the power output at the load condition of 120W. Since there is some load, we need taps to maximize the power at output. Because of load, the voltage across the system reduces. So to maximize the power at output, we need taps. Here we are using 3 tap. When 3 or more than 3 taps are used, the stage is progressed by one. Thus here it is stage 2. The voltage from the source is 237V. For which the corresponding current is 1.1A. Thus, the power output comes to be 258.2W/ 258.2VA as indicated in Table 6.

6.5. Tap Changing under Overload load condition

Now, the load has been increased by 40W. Thus, the above picture in Figure 9 shows the power output at the load condition of 160W. Since there is some load, we need taps to maximize the power at output. Because of load, the

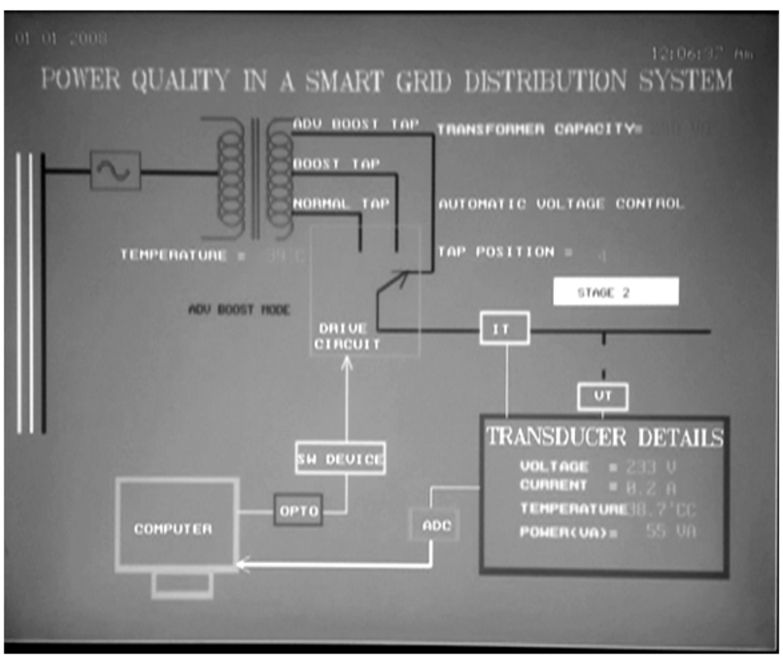

Figure 6: Power output corresponding to rated load condition

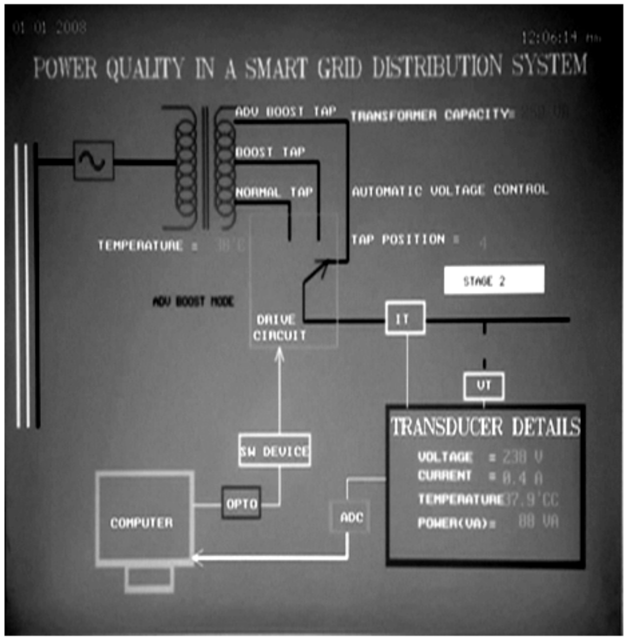

Figure 7: Power output corresponding to rated load of 237 V

Table 4
Readings related to rated load condition

Load Conditions	*Load of 40W*
Stage	1
Tap Number	1
Voltage	228V
Current	0.3A
Power	69.8VA

Table 5
Readings Related to Rated Load Condition

Load Conditions	*Load of 80W*
Stage	1
Tap Number	2
Voltage	232V
Current	0.7A
Power	163.5VA

voltage across the system reduces. So to maximize the power at output, we need taps. Here we are using 4 tap. When we use 3 or more than 3 taps, then the stage is progressed by one. Thus here it is Stage 2. The voltage from the source is 240V. For which the corresponding current is 1.5A. Thus, the power output comes to be 362.4W/ 362.4VA as indicated in Table 7. Recently electronic tap-changer has received more attention due to its quick response, better performance and simpler maintenance compared to the mechanical tap-changer that is manual tap changers. This project presents the capability of the distribution transformer equipped with an electronic tap-changer for improving power quality. At this end, the analytical computation for determining the compensating

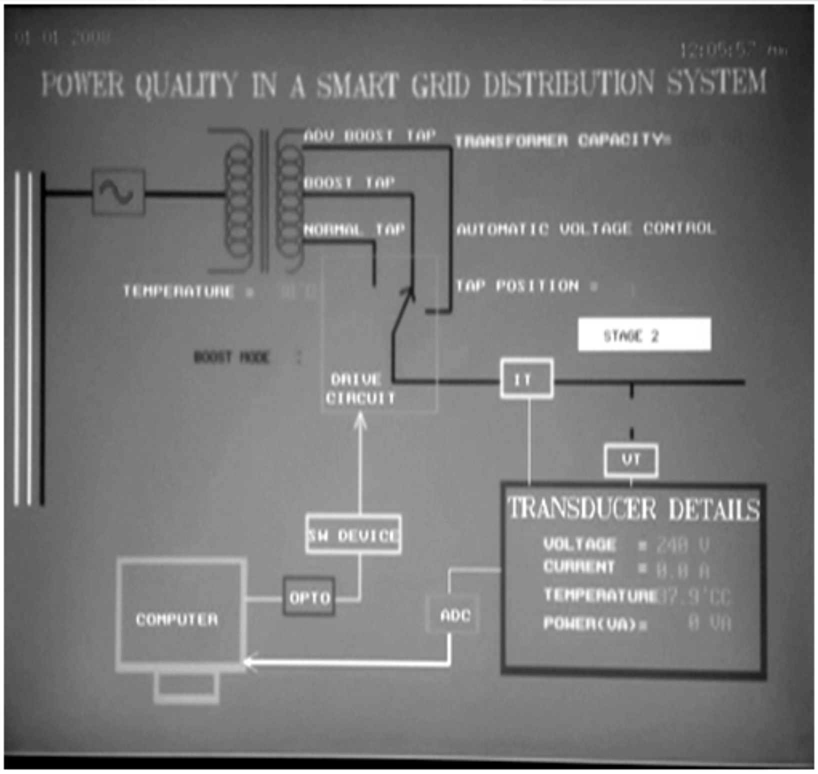

Figure 8: Power output corresponding to Overload load condition

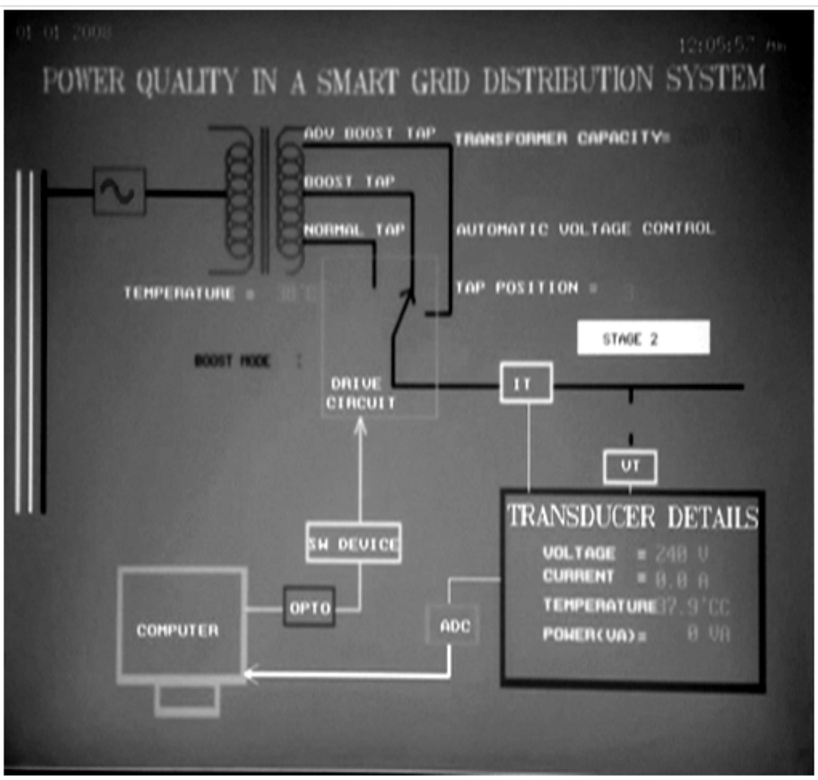

Figure 9: Power output corresponding to Overload load condition

limit of electronic tap-changer is given and then this system is simulated in order to show its capabilities for power quality enhancement. Meanwhile, the impact of the electronic tap-changer in power quality parameter improvement is compared with that of other custom power tools.

Table 6
Readings Related to Overload Condition

Load Conditions	*Load of 120W*
Stage	2
Tap Number	3
Voltage	237V
Current	1.1A
Power	258.2VA

Table 7
Readings Related to Overload Condition

Load Conditions	*Load of 160W*
Stage	2
Tap Number	4
Voltage	240V
Current	1.5A
Power	362.4VA

On load Tap Changer (OLTC) using fuzzy controller is used with higher capacity transformers. OLTC is a mechanism used in transformer for changing the tapping position on primary side (HV) of transformer. For any installation mostly in industrial areas and rural areas the voltage on HV of the transformer will not be 11KV (taking an example of 11KV System) and correspondingly the output will not be 433v. To maintain a constant 11KV/433V the tap changer on the Primary/HV side of the transformer is either raised or lowered to maintain constant 11kv input to transformer. Normally it is raised or lowered in steps of 2.5% of the rated KV value.

7. CONCLUSION

One of the major concerns in electricity industry today is power quality problems to sensitive loads. This can be overcome by using Smart Grids like OLTC's. Smart grids can offer several potential economic and environmental benefits like Improved Reliability and Highest asset utilization. The smart grid project model deals with automatic voltage control to maintain the smart grid system and the consumers to get the quality of power under all circumstances by changing the transformer tapping by measuring the grid voltage with the aid of the ADC and necessary interface circuits. The transformer provided in the smart grid project model consists of multi- tapping which is automatically changed by the computer with the aid fast switching drive circuits to maintain the grid voltage close to the rated normal voltage and thereby frequency also can be maintained close to normal frequency of 50 Hz.

REFERENCES

[1] Sujatha, K., Combustion Quality Estimation in Power Station Boilers using SVM based Feature Reduction with Bayesian, *European journal of Scientific Research, Elsevier,* Volume 120 No 2, pp.189-198, 2014.

[2] K. Sujatha, K. Senthil Kumar, T. Godhavari, R. S. Ponmagal, N. P. G. Bhavani, "An Effective Distributed Service Model for Image Based Combustion Quality Monitoring and Estimation in Power Station Boilers", Advanced Computer and Communication Engineering Technology, Lecture Notes in Electrical Engineering , Vol. 362, pp. 33-49, 2016.

[3] N.P.G. Bhavani, Dr. K. Sujatha, Soft Sensor for Temperature Measurement in Gas Turbine Power Plant, International Journal of Applied Engineering Research, pp.21305-21316, 2014.

[4] Sujatha, K. Pappa, N. Senthil, K. Kumar and Siddharth Nambi, U., Monitoring Power Station Boilers Using ANN and Image Processing, Trans Tech Publications, Switzerland, Advanced Materials Research, Vol. 631-632, pp.1154-1159, 2013.

[5] Sujatha, K. Pappa, N. Senthil, K. Kumar, Siddharth Nambi, U. and Raja Dinakaran, C. R., Intelligent Parallel Networks for Combustion Quality Monitoring in Power Station Boilers, Trans Tech Publications, Switzerland, Advanced Materials Research, Vol. 699, pp.893-899, 2013.

[6] Sujatha, K. Pappa, N. Senthil, K. Kumar, Siddharth Nambi, U. and Raja Dinakaran, C. R., Automation of Combustion Monitoring in Boilers using Discriminant Radial Basis Network , *Int. J. Artificial Intelligence and Soft Computing,* Vol. 3, No. 3, 2013.

[7] K. Sujatha, K. Senthil Kumar, T. Godhavari, R. S. Ponmagal, N. P. G. Bhavani, (2016),"An Effective Distributed Service Model for Image Based Combustion Quality Monitoring and Estimation in Power Station Boilers", Advanced Computer and Communication Engineering Technology, Lecture Notes in Electrical Engineering (LNEE), Vol. 362, pp. 33-49.

[8] Sujatha, K. and Pappa, N., Combustion Quality Monitoring in Power Station Boilers Using SVM Based Feature Reduction and RBF, TIMA-2011 Trends in Industrial Measurements and Automation, 2011.

[9] Soma ShekaraSreenadh Reddy Depuru, Lingfeng Wang, Vijay DevabhaktuniRobert C. Green in High performance computing for detection of electricity theft Ancillary Services: an overview of International Practices.: Cigre Working Group C5.06, 2010.

[10] K. Bhattacharya, M. H. J. Bollen, and J. E. Daalder, Operation of Restructured Power Systems.: Kluwer's Power Electronics and Power Systems Series, 2001.

[11] Y. Rebours, "A Comprehensive Assessment of Markets for Frequency and Voltage Control Ancillary Services," University of Manchester, PhD Thesis, 2008.

[12] F. Dong, B. H. Chowdhury, M. L. Crow, and L. Acar, "Mid-term voltage stability study using the quasi-steady state analysis method," in IEEE PES General Meeting, Toronto, pp. 2646-2651, 2003.