Low – Cost Multipurpose Platform for Distribution System Monitoring and Analysis with Sample Grid Applications

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Abstract—To prevent from severe functional difficulties in the power electrical distribution systems under the conditions of environmental limits, liberalization of the energy market and denationalization of the power supply production, where power systems are increasingly working at their utmost performance limits and frequency in order growth the strength of exploitation, the system's security and reliability in different characteristics of power system operation need to be monitored and maintained. As the necessities of power system operators (SOs) for wide area monitoring system to observe different states and stability of the power system to detect the power quality events and parameters permanently is definitely a major anxiety in the present days and its important rises with the uses of sophisticated devices whose performance is very sensitive to the quality of power supply. This paper is considered about the design and implementation of a low cost multipurpose platform (MPP) for the distribution system monitoring and analysis, which has the ability of analyzing power quality, logging event, measurement of synchronized phasor and inter-area oscillation all together in one device. As the harmonics is one of the main parameter of power quality, a system has been proposed in this paper for mitigating harmonic in the distribution side. The existing systems for power signal monitoring and analysis till now used only six voltage channels and six current channels. With increased number of input channels and use of some better algorithms for the different modes of operations, the result has been improved. The proposed device can therefore aid the requirements of modern electricity markets, encounter the multiple needs of the power SOs and transform an ordinary electricity utility into a system with smart applications.

Keyword – D-STATCOM, monitoring, power quality (PQ), Power system measurements, power system monitoring.

I. INTRODUCTION

The evolution of technology particularly the applications on power electrical over the years has conveyed a lot of technical amenities and cost-effective benefits. And hence new challenges in studies of power system operation have arisen. To prevent from severe functional problems happening under the circumstances of the exciting environmental limits, liberty on the energy market and denationalization of the power supply production, where power systems are increasingly working at their utmost performance limits and frequency further than them in order to increase the strength of utilization, the system's security and reliability in various aspects of power system operation needs to be maintained.

In present days, various devices and instruments with different technical features are commercially available in the market for power system monitoring and/or analysis. These are specific in one or more than one of power energy, synchronized phasor (synchrophasor), harmonics, light flicker, transient, event, and PQ measurements. Almost all of them use microcontroller and/or DSP based hardware. Though they are quite user friendly, their hardware and software are rigid, and hence do not allow the user to modify them for sustaining the probable measurement needs in the future. Most of them are more appropriate for the measurements in the distribution and utilization sides of the power system.

Lots of system methodologies and devices are proposed in the literature for power system monitoring and analysis. Some of these have been developed for the transmission and distribution systems with detailed on voltage quality and/or voltage harmonics. A system for detecting fault location in distribution system is proposed and implemented in Quebec, 2007[1]. A measurement system based on general purpose DAQ boards and high performance GPS receivers has been proposed and implemented by Carta, Locci, and Muscas in 2009 [2] which can estimate the harmonic synchrophasors in the end points of an electric distribution system.

A national wide monitoring system in real time has been presented in [3] and [4] to monitor all the power quality parameters and electrical related quantities of the power transmission system, counting the interfaces it has with the power distribution system and generation system in 2011.

With PQ and event monitoring and analysis, power system stability monitoring has also became a critical issue for system operators (SOs) to prevent brownouts and blackouts. Synchrophasor Standards have evolved since the introduction of the first one, IEEE Standard 1344, in 1995 [5]. In 2009, the IEEE started a joint project with IEC to harmonize real time communications in IEEE StandardC37.118-2005 with IEC 61850 communication standard. These efforts led to the need to split the c37.118 into two different standards: IEEE Standard C37.118.1-2011 [7] that now includes performance of synchrophasors under dynamic systems conditions and IEEE Standard C37.118.2.2011Synchrophasor Data Transfer for Power System [8]. The standard C37.118.1-2011 defines synchrophasors, rate of change of frequency (ROCOF) and frequency measurement under all operating conditions. An improved process for defining the harmonic distortion produced by customer and utility in a distribution system has also presented in the paper [9]. Multipurpose platform (MPP) for monitoring and analysing electrical distribution system which combines the various operations of power quality analysis, recording events, collection of data, measurements of synchronized phasors, identification of inter-area oscillation, and measurements of harmonic and flicker contribution all together in one device has been proposed [10].

This paper is considering about the design and implementation of a low cost multipurpose platform (MPP) for the distribution system analysis which has the ability of analysing power quality, logging event, measurement of synchronized phasor and inter-area oscillation all together in one device. The individual contributions of different loads supply from the same bus at a point of common coupling can also determine by embedding the algorithms of flicker and harmonics current contributions.

One of an important considerable constraint of power quality is harmonics. The source of harmonics associated problems that might occur by the customers with sensitive equipment could be located by harmonic current monitoring. As the eminence of power electronics like the voltage supplied by the utility or the current injected by the customer has become an important concern, the interest in finding describing and forecasting the above system behavior grows continuously. Harmonics in the power electrical distribution system represents a threat to sensitive equipment like adjustable speed drives, electric power loads, computers, etc. During the normal operation of this equipment, distortions are introduced to the steady-state current and voltages. And hence, we need to pay attention to the utility of electrical power distribution system and the issue of harmonic distortion.

The objective of monitoring power quality could be to diagnosis the incompatibilities available in the power system with load, refine modelling techniques, calculation of power electronics environment at the portion of the system in order and estimation of upcoming performance of load equipment or mitigating devices of power quality.

Multipurpose Platform which combines the various operations of power quality analysis, recording events, measurements of synchronized phasors, identification of inter-area oscillation all together in one device. And also with some measurements at a point of common coupling (PCC) such as the flicker contribution and the harmonic contribution measurements, and raw data collection should be carried out temporarily. The proposed MPP has the additional feature like reconfiguration of software and can be make programmed remotely via Internet or the existing fiber network of SO.

MPP hardware is a minicomputer based device, where different algorithms of various operating functions have been implemented. The proposed MPPs can also set up the building blocks of next generation SCADA systems in the future with high design flexibility. The MPPs can evolve an ordinary electricity system toward a smart grid, when integrated with a monitoring and control centre.

II. PROPOSED SYSTEM

An The proposed system is a low cost multipurpose platform for distribution system monitoring and analysis, which has the ability of analyzing power quality, logging event, measurement of synchronized phasor and inter-area oscillation with flicker and harmonic condition measurements at a point of common coupling (PCC) all together in one device. The proposed MPP software is reconfigurable. Minicomputer based hardware is used in MPP and hence various algorithms of different operating functions have been implemented. The MPPs can advance an ordinary power electric system to a smart grid, when integrated with a monitoring and control centre.

It is also mentioned in the paper [10] that with increase number of channels in input and some replacement of algorithms used for various operations and hardware in the existing MPP, it can be transformed to low cost multipurpose platform for distribution system monitoring and analysis.

The proposed system deals only on the distribution system so it will provide more reliability and accuracy with flexible design. The voltage interface unit and current interface unit channels have changed to twelve channels each while it was six channels each in existing one. And hence there are twelve single ended voltage signals and twelve differential current signals unlike existing system having both only six. Therefore we need the data acquisition unit with more channels, and so we used 48 channels programmable IOs DAQ unit instead of 24 channel DAQ unit used in existing system.

The mitigation of harmonic distribution is based on distribution static compensator (DSTATCOM) [11]. It has more reliable, fast response among the categories under the available custom power electric devices. Thus, the existing system has been modified into low cost distribution system monitoring devices.

III. MPP DESIGN

MPP is designed specifically to perform one or more of the operation modes as in existing MPP as given in table I. The general dataflow diagram of the developed software, which is common to all the operation modes of the MPP, is shown in figure 2. MPP is designed to collect three-phase, analog current, and voltage waveforms obtained from two different measurement points.

TABLE I. Operation Modes and Usage for Multipurpose Platforms

Operation Mode	Mode Usage	Computation Type
PQ Monitoring and Analysis	Continuous use for permanently connected MPPs	On-line
Event Logging	Continuous use for permanently connected MPPs	On-line
Synchrophasor Measurement	Continuous use for permanently connected MPPs	On-line
Power System Oscillation Monitoring	Permanent use for selected MPPs	On-line
Raw Data Collection	Temporary use for selected MPPs	Collected data is processed off-line
Flicker Contribution Measurement	Temporary use for selected MPPs	On-line or off-line
Harmonic Contribution Measurement	Temporary use for selected MPPs	Collected data is processed off-line

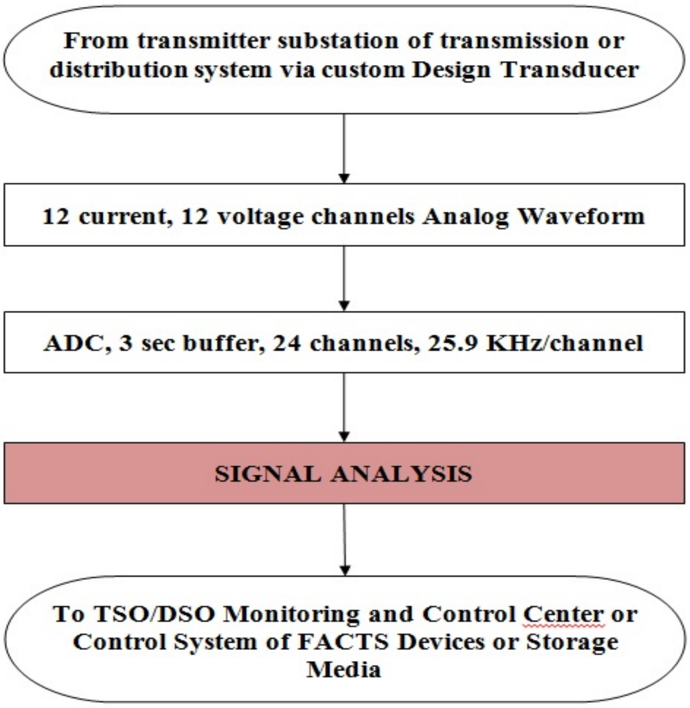

Fig. 1. Data flow diagram of the MPP software common to all the operation modes.

By means of the ASCC, the analog data are then converted to a suitable range which is to be input to the ADC. These data are then sampled at a rate of 30.72 kHz/channel, which resembles with 512 samples/cycle of the 60 Hz power frequency and then processed using 3-s buffers. Each buffer has goes through analyses by the application-specific signal analysis block of the corresponding operation mode. Analyses results are then served to the SO (TSO/DSO), or to the control system of a FACTS device, or they can also be stored into a suitable medium.

Signal Analysis block of each operation mode used different designs and algorithms.

- Power quality monitoring and analysis software is designed to comply with the IEEE Std. 1159 [13], IEC 61000-4-30 and IEC 61000-4-15 [14] standards.
- Synchrophasor Measurements are carried out according to IEEE Std. C37.118.1-2011 [7].
- Event-Logger software is according to IEC 61000-4-30 standard.
- Oscillation Identifier software operates on the frequency waveform of one voltage channels, and filtered out to eliminate the dc and noise components. DFT with 50-mHz resolution is applied on the filtered output to attain the oscillation components existing in the power system.
- Flicker contribution measurements are computed for individual load supplied from PCC according to the method described in IEC Standard 61000-4-15 [14].

Harmonic Current contribution of the loads supplied from PCC can be computed using multiple MPPs measuring load feeders. It is based on the distributed static compensator (D-STATCOM) [15].

IV. Methodologies Available for Harmonic Monitoring and Mitigation

There are various methodologies for harmonic compensation in distribution system:

- Static VAR compensator
- Series compensator
- Shunt Active Power Filter (SAPF) compensator
- Distributed Static Compensator (D-STATCOM)

TABLE II. Comparison of Various Harmonic Distribution Compensators

Static var compensator	**Series compensator**	**Shunt Active Power Filter compensator**	**Distributed Static compensator**
Associated with power system to normalize the transmission line voltage	Inserts reactive power elements into transmission lines	In current control mode, a voltage source converter based device is operated	Power factor improvement and voltage regulation for distribution system
Connected near large industrial loads to increase PQ	Reduces transmission line inductivity and transmission angle	Ease the weak load power factor. Also balances the source current for loads	Consist of a DC energy storage device, two level VSC and a coupling transformer
Used thyristor controlled reactor	Increase transfer capability	Phase shifted by 180°	Control is based on sinusoidal PWM
Result is unceasingly variable lagging or leading power	Increase system stability	By injecting equal and opposite harmonic compensating current, recompense current harmonics	Requires only to measure the rms voltage at the load point

Static var compensator, series compensator and shunt active power filter compensator operates mainly in transmission line. While distributed static compensator is especially for distribution line.

This paper is mainly considering the distribution system, and so distributed static compensator is chosen for harmonic distribution compensation.

Various harmonic mitigation techniques available are presented aimed for giving a review of harmonic extenuation methods dealing with power distribution systems.

Hence we can conclude that distributed static compensator (D-STATCOM) is best suited for this project, as it mainly concentrates on distribution system and is used in this project for reducing THD. So we go for simulation of the harmonic distribution system using D-STATCOM.

V. System Specifications

A D-STATCOM consists of a two level VSC, a dc energy storage device, controller and a coupling transformer connected in shunt to the distribution network. Figure 3 gives the schematic diagram of D-STATCOM.

$$I_{out} = I_L - I_S = \left((V_{th} - V_L) - Z_{th}\right) \quad (1)$$

$$I_{out} < \gamma = I_L < (-\theta) - (V_{th}/Z_{th}) < (\delta - \beta) + (V_L/Z_{th}) < (-\beta) \quad (2)$$

Where, I_{out}= Output current; I_L= Load current;I_S= Source current; V_{th} = Thevenin voltage; V_L = Load voltage; Z_{th}= Impedance.

Considering the equation 2, I_{out} will precise the voltage sags by regulating the voltage drop through the system impedance, $(Z_{th} = R + jX)$.

The efficiency of D-STATCOM in improving voltage sag rest on:

a) Impedance value, $Z_{th} = R + jX$

b) The load bus fault level

Voltage Source Converter is an electrical device that connected in parallel to the system which has the ability to produce a sinusoidal voltage with any essential phase angle, frequency and magnitude. It will either completely replace the voltage or insert the missing voltage. It also changes the DC voltage across storage devices into a set of three phase AC output voltages.

The VSC transforms the DC voltage across the storage device into a set of 3 phase AC output voltages which are in phase and coupled with the ac system over the reactance of the coupling transformer. Effective control of reactive and active power exchanges between the D-STATCOM and the ac system are done with appropriate changes of the magnitude and phase of the D-STATCOM output voltages. When VSC is connected to ac system in shunt, it offers a multifunctional topology which can be used for compensation of reactive power, voltage regulation and correction of power factor and elimination of the current harmonics.

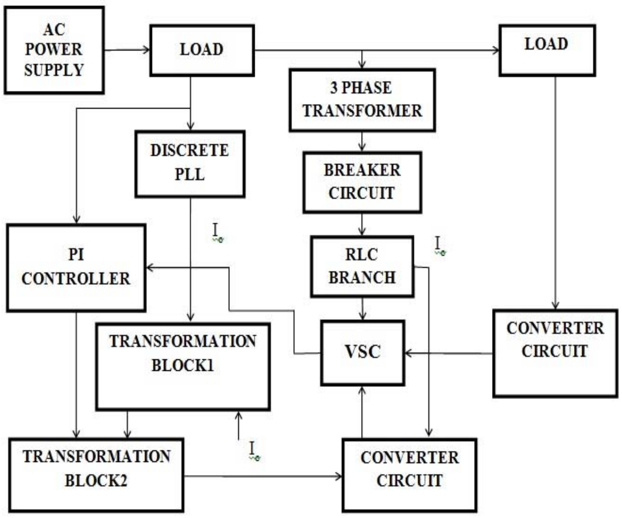

Fig. 2. Block diagram of the implemented system for THD mitigation

The D-STATCOM regulates the voltage at the point of connection and the control is based on sinusoidal pulse width modulation which only needs the quantity of rms voltage at the load point.

D-STATCOM has capability of producing or fascinating reactive power. If the output voltage of the VSC is more than AC bus terminal voltages, it is said to be in capacitive mode. Thus compensating the reactive power over AC system and adjusts missing voltages which are in phase and coupled with the AC system over the reactance of coupling transformers. Appropriate change in the magnitude and phase of the DSTATCOM output voltages allows operative control of active and reactive power exchanges between D-STATCOM and AC system.

PI Controller is a feedback controller driving the system to be controlled with a weighted sum of the error signal i.e. difference between the output and desired set point and the integral of that value. It will reduce the error signal to zero.

The load rms voltage is brought back to the reference voltage by comparing it with reference voltage.

The device which produces the sinusoidal Pulse Width Modulation signal is PWM generator. To make it operate, the angle is added to the phase angle of the balance supply voltages just as at 120°, producing the desired synchronizing signal. It also collected the error signal angle from PI controller. The moderated signal is related with a triangle signal to produce the switching signals for VSC valves.

As this paper is concerned about the multiple purposes which also include harmonic distribution measurement system, a system for mitigating harmonic distortion in the distribution system have been implemented. The block diagram of the Total Harmonic Distribution measurement is as shown in the figure 3.

VI. PERFORMANCE EVALUATION

The total harmonic distribution is compensated in the distribution system using distributed static compensator (D-STATCOM). The simulation is performed using MATLAB. And its results are illustrated as follows.

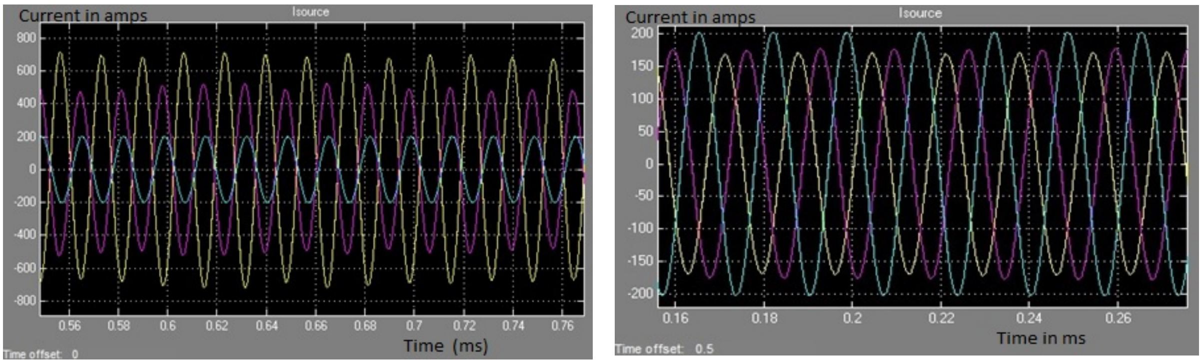

Fig. 3. Current signal at the load before implementing D-STATCOM (left) and Current signal components at the load after implementing D-STATCOM (right).

The left figure of figure 3 shows the current signal obtained at load before the implementation of D-STATCOM with its harmonic components.

The fundamental components and the 3rd harmonic and 5th harmonic components obtained from the distorted signal are also presented in the figure. And from this, we manually calculated the THD and it is 4.15 %.

Right side figure of figure 3 shows the current signal obtained in the distribution system load after the implementation of distributed static compensator (D-STATCOM).

It can be seen that the harmonic components are reduces, so that fundamental component dominated the harmonic components.

After the implementation of the proposed design for mitigating harmonics using D-STATCOM, the THD level is observed. And it has THD = 1.167 %. So it is reduced from 4.15 % to 1.167 % by implementation of the proposed system based on D-STATCOM for mitigating harmonics in distribution system.

We have the definition of Total Harmonic Distortion as the ratio of sum of powers of all harmonic components to the power of fundamental component.

$$THD = \frac{sum\ of\ powers\ of\ all\ harmonic\ components}{power\ of\ fundamental\ component} \quad (3)$$

It can be written as

$$THD = \frac{\sqrt{I_2^2+I_3^2+I_4^2+\ldots..+I_n^2}}{\sqrt{I_1^2}} \quad (4)$$

where, I_1 = fundamental frequency component; I_2 = 2nd harmonic component; I_3 = 3rdharmonic component and so on.

But, here the even harmonics are nullified and so it has become as $THD = \frac{\sqrt{I_3^2+I_5^2+I_7^2+\ldots..}}{\sqrt{I_1^2}}$ (5)

From the current signal, we observed before the implementation of D-STATCOM, we obtained these components as $I_1 = 200$, $I_3 = 430$ and $I_5 = 710$.

Therefore, $THD = \frac{\sqrt{430^2+710^2}}{\sqrt{200^2}}$ = 4.15 %

And after the implementation of D-STATCOM i.e. compensation of harmonics, the resultant waveform of the proposed system observed. The harmonic components are obtained from the waveform as $I_1 = 200$, $I_3 = 430$ and $I_5 = 710$.

Therefore, $THD = \frac{\sqrt{160^2+170^2}}{\sqrt{200^2}} = 1.167$ %

HENCE, THD IS REDUCED FROM 4.15 % TO 1.167 % USING D-STATCOM.

VII. CONCLUSION

The Multipurpose Platform presented in this paper is a compact, robust, and flexible environment, which is able to satisfy various needs of distribution system analysis and monitoring all in one device. The wide-area power system monitoring and analysis employing MPPs can be used to improve the efficiency, reliability, quality, and sustainability of electricity services. MPP hardware is upgradable and software is reconfigurable, it may reach much more powerful computation and analysis capacity in the future, with the advents in minicomputer technology.

D-STATCOM compensator has found to be best suited for harmonic mitigation in the proposed system and it is used for compensating harmonic distortion in the electrical distribution system.

The simulation of the proposed system for mitigating harmonic distortion in the distribution system is done using MATLAB and the results were analysed above. And the harmonics are reduced from 4.15 % to 1.167 %. In existing MPP, it concerned only on the measurements of harmonics. And the results are better than the provided result of existing multipurpose platform (MPP) for power system monitoring and analysis.

We can get a better MPP device by embedding synchrophasor measurement unit having better algorithm for power quality improvement in this proposed MPP. So implementing synchrophasor measurement, event logging and flicker measurement can be the future enhancement to improve the performance and area of the proposed system. Therefore the proposed all-in one MPP can meet the multiple requirements of the power SOs to serve the needs of modern electricity markets and it can also constitute the building blocks of next generation SCADA systems in the future with high design flexibility. Integrating with a monitoring and control center, the MPPs are very effective tools to evolve an ordinary electrical system toward a smart grid.

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