TEST Engineering & Management

May-June 2020
ISSN: 0193-4120 Page No. 10602 - 10610

Design and Development of Sag & Swell Hybrid Compensator for Voltage Flickering in Grid Loads

[1] P.Sundaramoorthi, [2]Dr.V.Prasannamoorthy
[3]Dr .R .Kathiravan
[1]Research Scholar
PeriyarManiammai University, Vallam, Thanjavur
[2] Assistant Professor (senior grade, Electrical and Electronics Engineering) Government College of Technology Coimbatore, Tamilnadu, India
[3]Prof &Head/Aerospace Engineering PeriyarManiammai University, Vallam, Thanjavur, Tamilnadu, India.

Article Info
Volume 83
Page Number: 10602 - 10610
Publication Issue:
May - June 2020

Article History
Article Received: *19 November 2019*
Revised: *27 January 2020*
Accepted: *24 February 2020*
Publication: *18 May 2020*

Abstract:
This paper presents power quality for industrial power distribution system due major sensitive loads arises on voltage sag and swell. The proposed compensator system decreases the size of power electronic components and reducing voltage stress. Flicker issues affect the power factor of electrical system; a proposed system design is maintain a constant power factor by minimizing the sag and swells components on the load side which reduces current ripple in power delivered to load. The control on compensation voltages are fed using solar PV panel power stored in the battery. The design of STATCOM parameters are considered an optimization problem according to the time domain-based objective function solved by optimization firefly algorithm. Excessive power generation and swell power is cut-off and fed into battery by proposed converter system. The system has a minimum number of switches during computation and conducting time of voltage sag and swell which reduces overall power electronic switches power losses. Initially proposed system is validated using MATLAB-SIMULINK and experimentally validated using a prototype of the digital SpicProgrammable Interface Controller.

Keywords: *sag; swell; compensator; flicker; MATLAB; dSPIC.*

1. Introduction

Electrical power quality performance creates a hard impact on real time distribution power systems (DPS).Due ineffective power quality system year by year power sector losses its outcome product and drastic in economic loss in each every power industrial sector [1] with the issues related to low power quality. In effective power quality related to voltage sag and swell which is directly associated with flickering issues in the load side. The electrical system even causes of other types of issues related to harmonic currents distortions which can lead to poor power quality delivery. Many industrialists and researches propose the voltage sag is major concern of power quality which is reported as the major electrical power distribution problem [2, 3]. Voltage sag and swell compensation is required for load that operates range from a few hundred watts to several megawatts [4]. Many researchers are used to different strategies employed to solve voltage sag and swell issues, such as the hybrid compensator type. A compensator is a system that connected with power-electronic-device, which is connected in series with the electrical distribution system, a compensator type also design to protect critical loads and pay loads from the supply side which has disturbances such as voltage sag and swell [5]. Fig.1 illustrates a typical scenario of a hybrid compensator application in medium-voltage (mv) level. It should be noted that δy transformers are often used topreventzero sequence components from propagating to the secondary side of the transformer during an unbalanced fault in an upstream point of the distribution system [6]. For compensator a storage device is required to deliver compensation voltage, various types of storage device is available such with rechargeable energy storage technologies based on superconducting magnets (SMEs), flywheels (fess), batteries (bass), and ultra-capacitors (ucaps) is compared[10] for integration with power electronics circuits to form as hybrid compensator and techniques. Efforts have been made to integrate energy storage into the hybrid compensator system, which will give the system active power capability that makes it independent of the grid during voltage disturbances. In [7], cascaded h-bridge-based hybrid compensator with a thyristor-controlled inductor is proposed to minimize the energy storage requirements. In [8-16], flywheel energy storage is integrated into the DVR system to improve its steady-state series and shuntcompensation.

In this paper, we propose an ac-dc driver consisting of two parallel inverted buck converters for reducing light flicker to low-risk levels. Todistribute the power differences between the twice-line-frequency of input power and the constant power, one inverted buck converter conveys energy from the ac source to a storage capacitor, simultaneously performing the PFC operation.

2. Proposed System Architecture and Operation Principle

The other inverted buck converter supplies a constant current to the grid to maintain a constant brightness. The proposed architecture can achieve an input power factor higher than0.9. Although the proposed approach offers a lower power factor than the conventional two-stageA approach with a boost PFC converter [9], The power structure with two inverted buck converters in parallel significantly reduces the average voltage at the input voltage of 110 Vrms, whereas the average voltage of battery in the two-stage must be higher than 155 V. Moreover, the size of battery is reduced because less than 30% of the output power is initially stored in battery and then delivered to the gridload.

Fig. 1 illustrates the overall architecture of the proposed LED driver that consists of a full bridge rectifier, an EMI filter, two parallel inverted buck converters, and an on-chip controller IC. The upper inverted buck converter composed of *M*1, *L*1, *D*1, *D*2, and *C*STO performs the PFC function while simultaneously transmitting energy from an ac source to a storage capacitor *C*STO, to buffer the instantaneous power differences between the input power and the output LED power. The other inverted buck converter consisting of *M*2, *L*2, *D*3, and *C*OUT regulates the output current to maintain the brightness of the LEDs to reduce light flicker. The EMI filter suppresses electrical noises from the ac source and the switching circuits and shapes the ac input current for thePFC.

The duty cycle of the switches *M*1 and *M*2 controlled by a digital control logic composed of programmable digital loop filters (DLFs) and digital pulse width modulators (DPWMs). For a 10 bit DPWM, the upper 6-bit resolution is realized by a counter-based DPWM, and the lower 4-bit resolution is obtained by a phase interpolator circuit to improve the input clock frequency requirement [11]. For example, if the input clock frequency is 64 MHz, the output switching frequencyis1 MHz Inverted buck converters (also known as floating buck converters) have been widely used as current regulators in dc-dc [12], [13] and ac-dc LED drivers [8], [9], [14], [15]. While the traditional buck converter with a high-

May-June 2020
ISSN: 0193-4120 Page No. 10602 - 10610

side switch requires additional bootstrapping circuits, the inverted buck converter with a low-side NFET can be easily driven by a gate driver circuit. Therefore, the proposed ac-dc LED driver with AC input is given through the Auto Transformer to create artificial sag and swell. The potential Transformer used to step down high voltage of few kilo volts to few volts. For Voltage measurement, ZCD detector used for frequency synchronization, and they are given to PIC microcontroller (PIC 16F877) and also displayed onLCD.

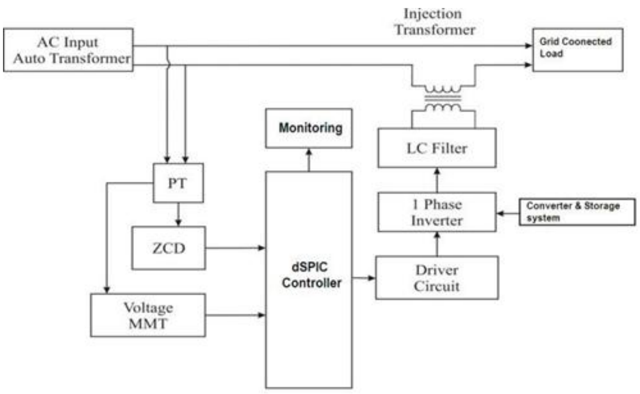

Figure 1.Proposed Electrical Power Compensation System

Driver circuit consists of an optocoupler which isolates microcontroller and single phase inverter as their operating ranges are different. A 12V DC given to single phase inverter, and this converts DC to AC. The circuit consists of MOSFETs as switching devices so that the hybrid compensator will operate based on the firing pulses. LC filter removes the higher order harmonics present in the AC after being inverted from DC. Then inject that reactive power into the transmission line. Then the voltage is thus injected through a series connected InjectionTransformer.

3. Design of Compensator

Electrical power system is composed of grid with the compensator attached as shown in Fig.2 System is composed of a multilevel single-phase converter connected loads in series such as the utility loads in domestic areas and corresponding terminals. The power electronic circuits is composed of transformer-less with series active filter and a five-level NPC converter [16] illustrated in Fig.3 As the connection is connected series between the utility load and distribution transformer. To filter high switching frequency and generated harmonics, a passive device based filters is designed at the output of the power converter.

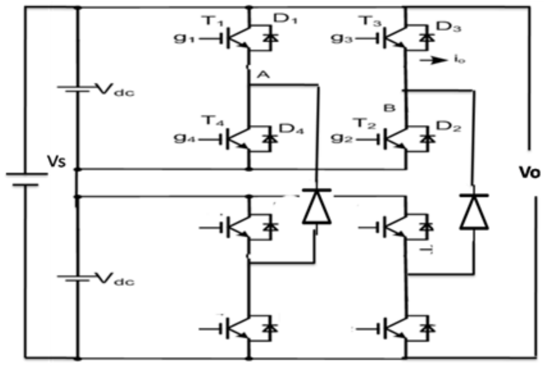

Figure 2. Proposed Compensator Circuit Diagram

A passive device bank of tuned passive filters confirms a low impedance path for harmonics generated in system feed to the load. The converter and compensator confirm fast transient response with sufficient better stability margins which is applied to wide range of dynamic operations of system.

The hybrid compensator is designed to connect in series to inject the compensating voltage in electrical distribution system. In dc to dc converter side of the compensator and auxiliary dc-link energy storage system is installed. The active compensator's control structure depicted in Fig.2 explains the four thyristors and feedback diodes activated with corresponding PWMsignals.

4. Design of hybridCompensator

In this section proposed compensator design parameters of a proposed with the considering reactive power compensation range and total harmonic distortion.

May-June 2020
ISSN: 0193-4120 Page No. 10602 - 10610

4.1 Design of L and C filter

Based on the required reactive power compensation range and parallel in composition with the parallel inductor (L) and capacitor (C) is used as filter and according the L and C can becalculated.

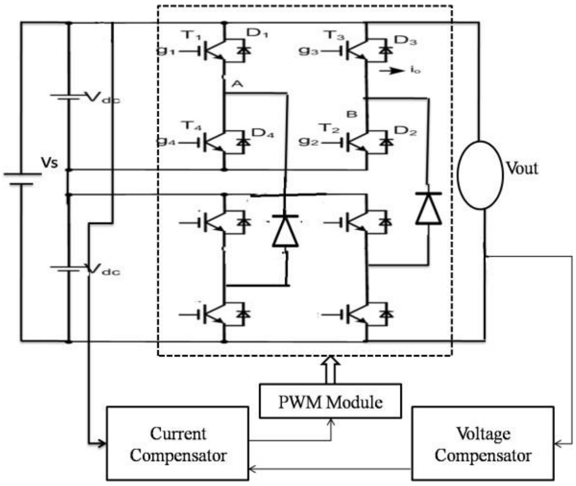

Figure 3. Model of the Voltage and Compensator and Controller

4.2 Design of hybridCompensator

Through the harmonic currents rejection and compensation voltage injection, the design criteria of the coupling Lc can set with corresponding design. With the proposed design of Lc, the problem of harmonic currents injection by the thyristor controlled part can be significantly alleviated with corresponding PWM signals.

4.3 Design of power electronicsswitches

Proposed controller is implemented in MATLAB simulink as real-time simulator for proposing compensator system. Real- time measurement of electrical variables is performing the measurement parameter is acknowledged in Table I. Input supply voltage is connected with as 120 Vrms is connected to a 1-kVA as non-linear load.

Thyristor compensator can be considered as a pair of bidirectional switches as shown which performs as voltage follower type generates low order harmonic currents when the switches change their states. Through the harmonic currents rejection analysis, the harmonic current orders generated can then be deduced in terms of Lc.Therefore,with appropriate design of Lc, the harmonic currents injection by the controlled thyristor part can bereduced.

5. Simulation ProposedCompensator

The simulation of the system with hybrid compensator is shown in Fig.4. By considering different types of faults such as transmission side faults, distribution side faults, faults due to the sudden connection of loads. A typical fault may occur due to any of these reasons.

5.1 Simulationmodel

A three phase load is considered with input voltage for proposed hybrid compensator as shown in Fig.4. A star-delta transformer is used for load sharing as well as for reducing the number of terminals. Due to different faults occurring in the system voltage sag is occurring. The input and output waveforms of the system show the sagconditions..

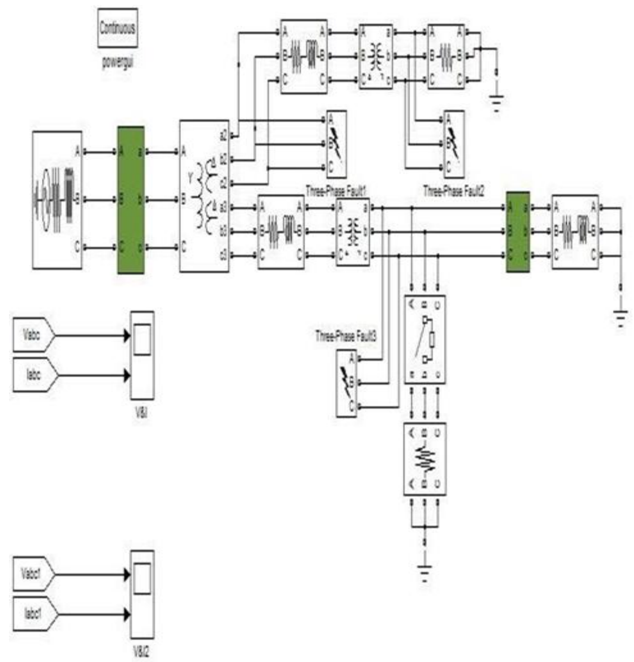

Figure 4. Simulation Layout ofthe System Hybrid Compensator

May-June 2020
ISSN: 0193-4120 Page No. 10602 - 10610

5.2Algorithmdesign

Fireflies are unisex so that one firefly will be attracted to other fireflies regardless of their sex. • The attractiveness is proportional to the brightness, and they both decrease as their distance increases. Thus for any two flashing fireflies, the less one will move towards the brighter one. If there is no brighter one than a particular firefly, it will moverandomly.

The brightness of a firefly is determined by the landscape of the objective function. There is a sudden decrease in voltage and a corresponding increasing in current as in Fig.6. This fault compensated by hybrid compensator.At first, a system designed without any hybrid compensator, and many faults introduced into the system for analysis purpose which shown in Fig.7.The faults are introduced to reduce the quality of the system. And a heavy load is suddenly connected to produce sag in the supply which shown in a drastic effect on the input side. Due to this effect, the output will have voltage sag as shown inFig.6.

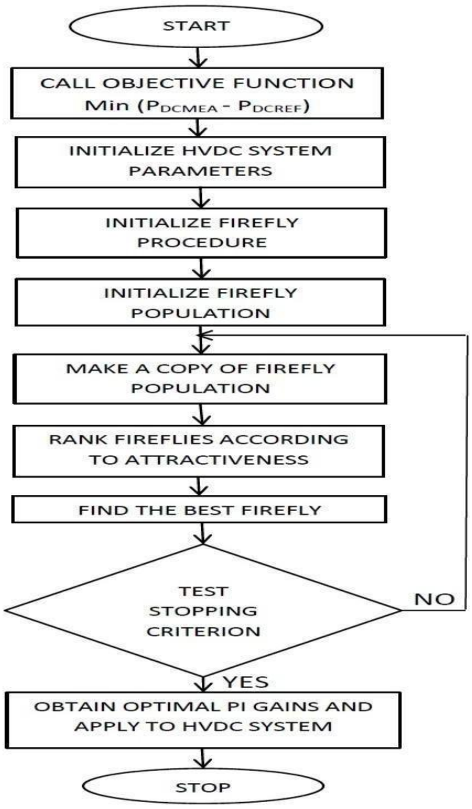

Figure 5. Algorithm flowchart

As the algorithm flowchart of hybrid compensator in figure 5 outputs. Here the voltage and thus current is being compensated by hybrid compensator. Basically hybrid compensator consists of a voltage source (battery) from which a voltage is injected through the subsystem to the transmission line.

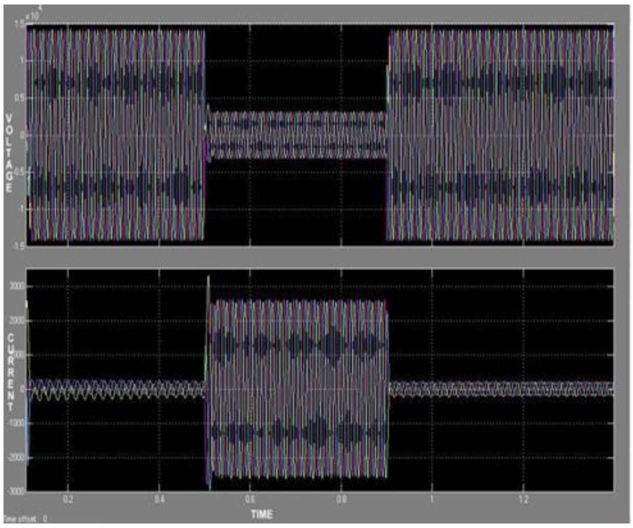

Figure 6. Input Voltage and Current Waveforms ConventionalCompensator

Nature-inspired metaheuristic algorithms have gained popularity, which is partly due to their ability of dealing with nonlinear global optimization problems. We have reviewed the fundamentals of firefly algorithm, the latest developmentswith diverse applications. The subsystem consists of injection transformers along with breakers in three phases. The hybrid compensator takes output side current as reference (Iabc) whose magnitude alone is compared in a magnitude and phase comparator (phase is neglected using terminator) and the output is given to a PI controller which will produce proportional and integral error according to output of comparator.

This error is given to discrete PWM generator which will generate pulses according to the input and it is fed to voltage source inverter made of MOSFET. Simultaneously the energy storage device will inject the voltage to the transmission

ISSN: 0193-4120 Page No. 10602 - 10610

line according to switching ofIGBT.

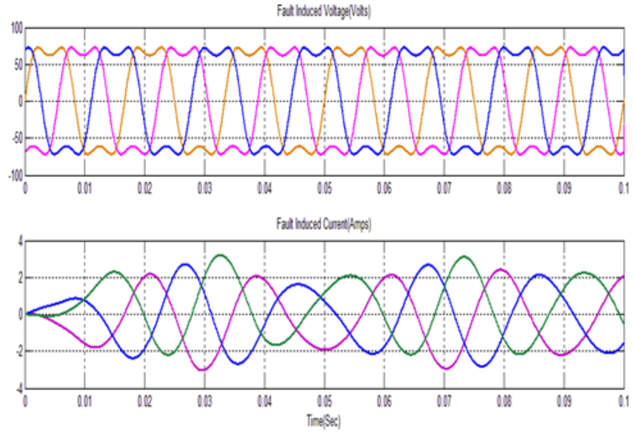

Figure 7. Output Voltage and Current Waveforms for the System With Conventional Compensator

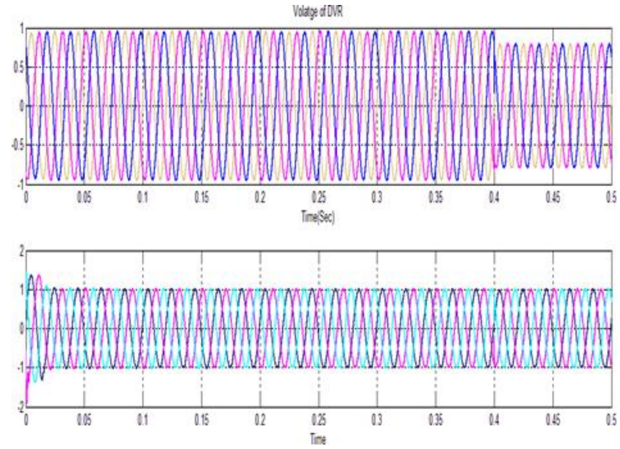

Figure 8. Input Voltage and Current Waveforms for the System With Hybrid Compensator

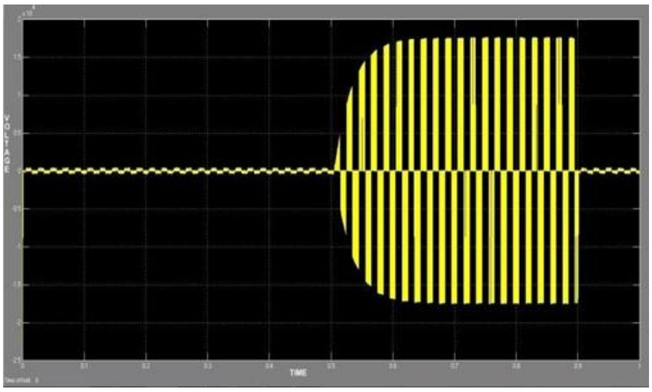

Figure 9. Output Voltage of with Hybrid Compensator

The voltage is being injected through a subsystem which consists of three injection transformers (one in each phase) which is connected to the transmission line through the breakers. The input to hybrid compensator is shown in Fig.8.The input is uncompensated voltage andcurrent

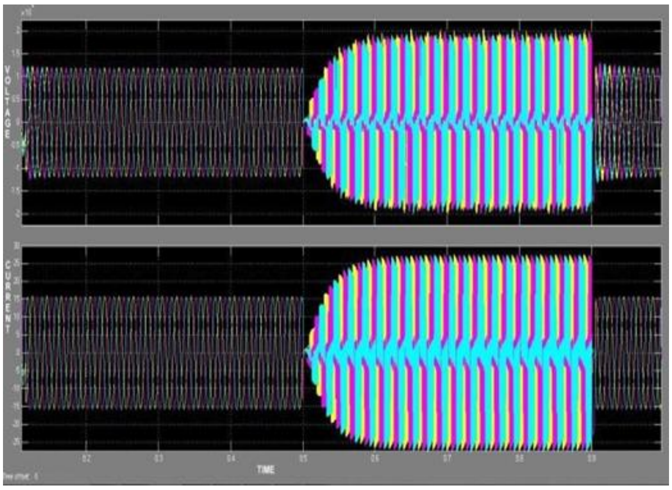

Figure 10. Output Voltage and Current Waveforms for the System with Hybrid Compensator

Power electronics MOSFET based switch converters connected in back to back configuration as compensator to deliver desired flicker voltage to compensate the load voltage against sag and swell. Compensated voltage by injecting a voltage in series with supply voltage with the help of injection transformer connected between supply and load. The performance of proposed hybrid compensator is implemented in MATLAB tested with detailed simulation results inMATLAB.

The output of the hybrid compensator is shown in fig.8 and it represents hybrid compensator is injecting the voltage on the duration of the sag and swell occurrence. Fig. 10 is the amount of voltage and current of the system has been compensated simultaneously with help of hybrid compensator.

6. Hardware setup in realtime

Compensator for electrical distribution system is implemented with corresponding LC filter to reduce harmonics ripples. A hardware with proposed logic based on MOSFET switches and corresponding filter design is constructed as shown inFig.10.

6.1Designspecifications

The complete proposed compensator is shown; Step down Transformer (0-9V, 15-0-15V, 1A), Bridge Rectifier, Potential Transformer (0-6V), Voltage Measurement Circuit (1458), Zero Crossing Detector (LM741), Pic Microcontroller (16F877A), Optocoupler (FOD817), Driver Circuit (IR2110), MOSFET (IRF840), LC filter, Injection Transformer, 36v Battery and a Load (Resistive), thus the voltage variation when the sag and swell is occurred in the system.

Figure 11. Hardware Prototype of the Hybrid Compensator Complete System

Table 1. Proposed Sag and Swell Voltage EfficiencyCalculation

Percentage for amount of voltage disturbance	**Percentage of directly processed power**	**Percentage of power fed from converter**	**Calculated efficiency overall**
50% of swell condition	50%	50%	98.5%
40% of swell condition	60%	40%	98.6
20% of swell condition	80%	20%	98.9
Normal state	100%	0	100%
20% of sag condition	80%	19.95%	98.4%
40% of sag condition	58.8%	41.2%	97.5%
50% of sag condition	42%	48.5%	98.2%

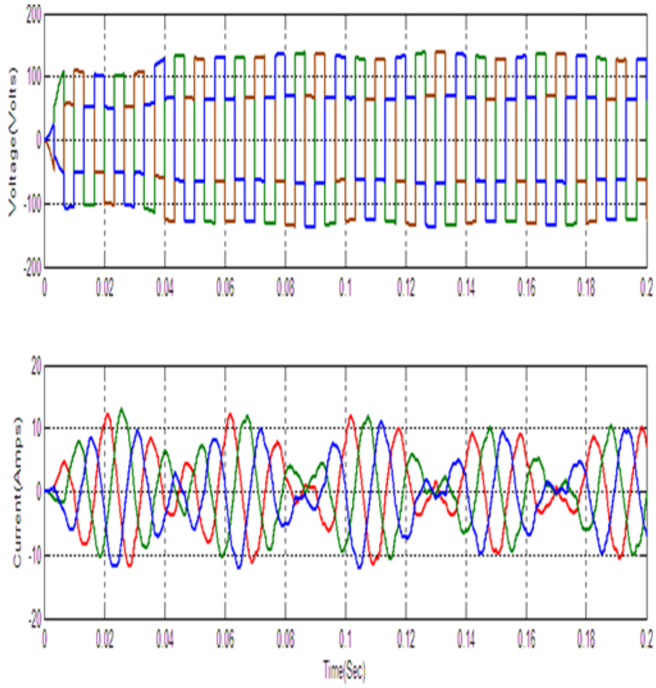

Figure 12.Output of Current and Voltage

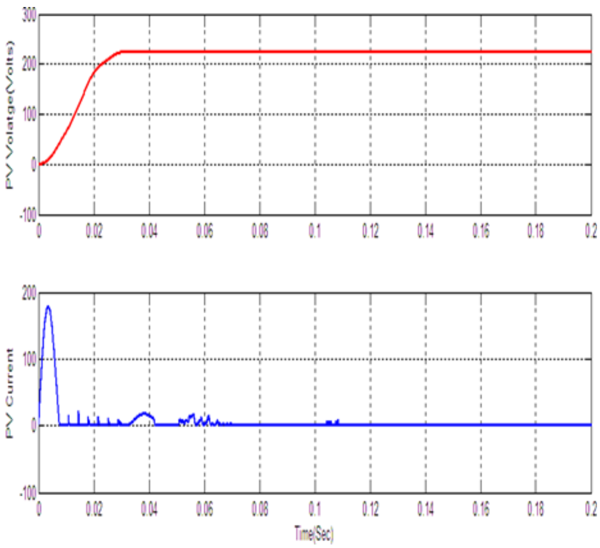

Figure 13. Wind Energy Conversion Output

Hybrid compensator is designed to reduce

May-June 2020
ISSN: 0193-4120 Page No. 10602 - 10610

the power quality problems such as sag and swell tested for critical loads. Hybrid compensator parameters is proposed and discussed with the considerations of its reactive power compensation range and the harmonic currents rejection analysis asfig.13.

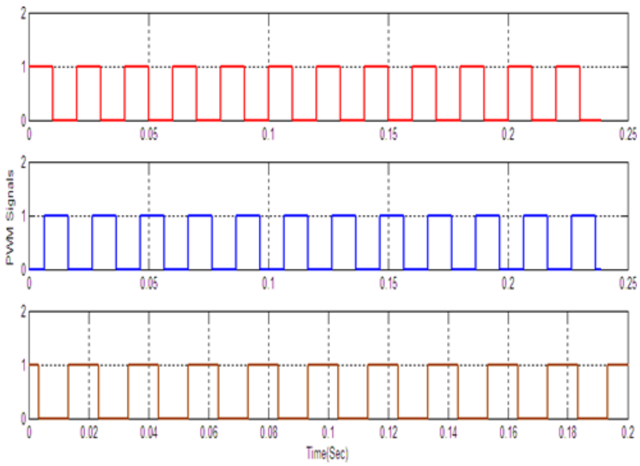

Figure. 13 PWM Generation for Compensator

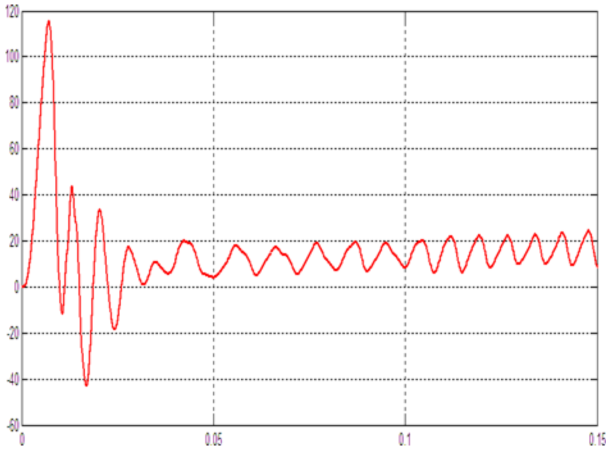

Figure 14. Voltage Disturbances in System

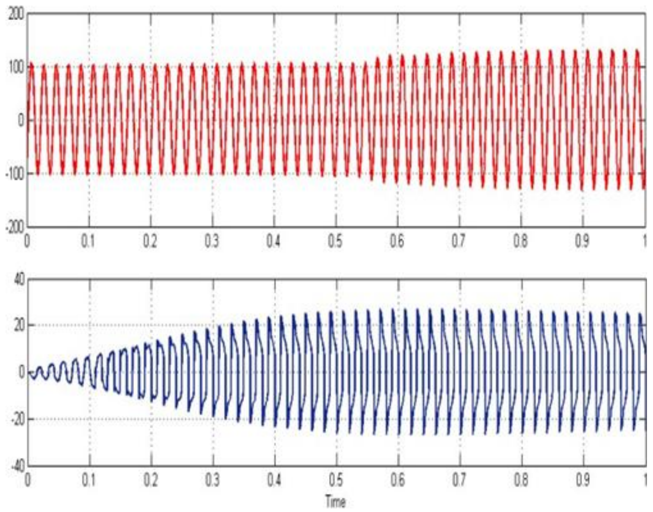

Figure 15. Output of Voltage and Current of ProposedCompensator

7. Conclusion

An integrated compensator algorithm was presented in this paper, which able to detect and classify the exact faulty phase even when the compensation level varies during inductive and capacitive modes of STATCOM operation presented. This fault location, fault type, fault inception angle, fault resistance, varying source impedance, change in power flow direction and CT saturation has negligible impact on the performance of the proposed method, more reliable and secured protection of STATCOM connected transmission system is possible. Simulation result are shown for voltage sag and swell with resistive loads all conditions under unity power factor mode and mitigates power quality issues with error distortion of 18.4% and in proposed system reduced to 5.2%. The system has also obeyed to IEEE-1547 and IEEE-519 standards as the prototype of hybrid compensator is developed with the help of Kerala State Electricity Board. From the experimental results, it is concluded that hybrid compensator is successfully able to compensate for voltage sag andswell.

REFERENCES

[1] AbdullahiBalaKUNYA,TankutYALCINO, Gaddafi Sani SHEHU "Voltage Sag And Swell Alleviation In Distribution Network Using Custom Power Devices; D-STATCOM and DVR" IEEE International Power Electronics and Motion Control ConferenceExposition,Turkey Pages:400 – 405,2014.

[2] Gabriel MejíaRuiz, Juan M. Ramirez "Transient voltage compensation by a power electronics-based device" IEEE PES General Meeting Conference Exposition andNational Harbor, MD pages: 1-5,2014.

[3] Suma Jothibasu , Mahesh K. Mishra "An

May-June 2020
ISSN: 0193-4120 Page No. 10602 - 10610

Improved Direct AC-AC Converter for Voltage Sag Mitigation" IEEE Transactions On Industrial Electronics (To be published infuture)

[4] DominikSzabó, Roman Bodnár, Michal Reguľa, Juraj Altus "Designing and modelling of a DVR in MATLAB" IEEE Electric Power Engineering (EPE), Proceedings of the 15thInternational Scientific Conference, Brno pages: 229-233,2014.

[5] AnkitPandey, Rajlakshmi "Dynamic Voltage Restorer and its application at LV and MV level" International Journal of Scientific and Engineering Research, volume 4, issue 6, Pages: 668-671,2013.

[6] A. Elnady and M. M. A. Salama, "Mitigation of voltage disturbances using adaptive perceptron-based control algorithm," IEEE Trans. Power Del., vol. 20, no. 1, pp. 309–318, Jan.2005.

[7] P. F. Ribeiro, B. K. Johnson, M. L. Crow, A. Arsoy, and Y. Liu, "Energy storage systems for advanced power applications," Proc. IEEE, vol. 89, no. 12, pp. 1744–1756, Dec.2001.

[8] H. Akagi, E. H.Watanabe, and M. Aredes, Instantaneous Reactive Power Theory and Applications to Power Conditioning, 1st ed. Hoboken, NJ, USA: Wiley, Piscataway, NJ, USA: IEEE Press,2007.

[9] S. Santoso, M. F. McGranaghan, R. C. Dugan, and H.W. Beaty, Electrical Power Systems Quality, 3rd ed. New York, NY, USA: McGraw-Hill,Jan.2012.

[10] J.Mangalanathan "Hardware Implementation of single phase Dynamic Voltage Restorer in mitigating voltage sag and swell" International Journal of Innovative Science'', Volume1, Issue 3, Pages: 187-193, 2014.

[11] Y. Lee, T. Kang, and J. Kim, "9-11-Bit Phase-Interpolating Digital PulsewidthModulator With 1000x Frequency Range," *IEEE Trans. Industry Applications*, vol. 51, pp. 3376-3384, Jul.2015.

[12] V. Anghel, C. Bartholomeusz, A. G. Vasilica, G. Pristavu, and G. Brezeanu, "Variable Off-Time Control Loop for Current-Mode Floating Buck Converters in LED Driving Applications," *IEEE J. Solid-State Circuits*, vol. 49, pp.1571-1579, Jul.2014.

[13] D. Park, Z. Liu, and H. Lee, "A 40 V 10 W 93%-Efficiency Current- Accuracy-Enhanced Dimmable LED Driver With Adaptive Timing Difference Compensation for Solid-State Lighting Applications,"*IEEE J. Solid-State Circuits*, vol. 49, pp.1848-1860, Aug. 2014.

[14] P. Athalye, M. Harris, and G. Negley, "A Two-Stage LED Driver for High-Performance High-Voltage LED Fixtures," in *Proc. IEEE Applied Power Electronics Conf*., 2012,pp.2385-2391.

[15] S. Lim, D. M. Otten, and D. J. Perreault, "New AC-DC Power Factor Correction Architecture Suitable for High Frequency Operation," *IEEE Trans. Power Electronics*, vol. 31, pp. 2937-2949, Apr.2016.

[16] H.-C. Kim, C. S. Yoon, H. Ju D.-K. Jeong, and J. Kim, "An AC- Powered, Flicker-Free, Multi-Channel LED Driver with Current-Balancing SIMO Buck Topology for Large Area Lighting Applications," in *Proc. IEEE Applied Power Electronics Conf*., 2014, pp.3337-3341.