Development of Generalised Integrator with a Feedback Loop Based Dynamic Voltage Restorer for Fast Mitigation of Voltage Sag/Swell

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Abstract:
Power-electronic converter-based device called the Dynamic Voltage Restorer (DVR) is intended to shield delicate loads from supply-side voltage perturbations. It is connected in series to the distribution feeder and has the ability to generate or absorb real and reactive power at its AC terminals. This work presents the use of a control scheme based on Generalized Integrator with a Feedback Loop (GIFL) gain choosing technique for the purpose of fast voltage sag/swell detection to enable the DVR to carry out a fast and effective voltage compensation in power distribution system. This helps in significantly reducing the impact of voltage sag/ swell and in turn improve the power quality of the system. Two scenarios were used to analyze the effectiveness of the developed technique: incorporation of voltage sag and swell independently on the distribution system. The results obtained showed that the distortions introduced to the system as a result of the sag and swell was significantly reduced. The results obtained from the developed scheme was further compared with that obtained when the conventional DVR was used in mitigating the voltage sag and swell using total harmonic distortion (THD) as performance metrics. All modelling and analyses were carried out using MATLAB 2019 software.
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Keywords: Converters, Dynamic voltage restorer, Generalized Integrator with Feedback, Injection transformer.

1. INTRODUCTION

A A few years ago, Electricity users' top worry was the supply's dependability [1]. Electric supply continuity can be used to define reliability (Singh et al., 2014). However, consumers nowadays are looking for more than just dependability; they also value quality [2, 3]. For instance, whenever a heavy motor load is turned on, a consumer connected to the same bus may experience a severe sag in supply voltage (Mahmoud et al., 2017). According to [4, 5] sensitive loads such as hospitals (life support, operating rooms, patient database systems), financial institutions, processing plants (semiconductor, food, rayon, and fabrics), air traffic control, and many other data processing and service providers require high-quality, reliable power. A relatively brief voltage sag can ruin a batch of goods in a number of operations, including semiconductor production and food processing facilities. Such customers are always concerned about such sags since each of such interruption as a severe consequence [6]. Such brief sags are enough to trigger contactor failure on motor drives. A process stoppage can ruin the circumstances for product quality control and necessitate restarting production [7]. Customers today want higher quality power, hence the term Power Quality (PQ) is given more significance [8, 9].
Now the significance of electric power quality has been increasing in the industries a result of an increase in demand for electric energy [10]. According to [11], voltage sag and voltage swell are two common disruptions of power quality issues in distribution systems. A decrease in RMS value of voltage less than 1 p.u. (per unit) is referred to as voltage sag. Additionally, a voltage swell is a brief increase in magnitude that is greater than 1 p.u. According to IEEE 1159-2009 standards, voltage sag/swell can last anywhere from a half-period to a minute [12]. The two types of voltage sag and swell which can occur on any distribution lines are symmetric and non-symmetric [13]. To mitigate these problems, Custom Power Devices (CPDs) are used [14]. Mitigation of voltage sag/swell is done by Flexible Alternating Current Transmission Systems (FACTS) device and CPDs [15]. In a power system, mitigation of voltage sag/swell is mostly done by CPDs located between sensitive load and grid. Sag/swell detection method plays an important role in effective compensation. To realize effective compensation, voltage sag/swell must be detected fast and accurately [16].
The most flexible and attractive way to reduce power quality (PQ) problems is to use converter based power electronic devices such as DV), Distribution Static Compensator (DSTATCOM), Uninterruptible Power Supply (UPS), Unified Power Quality Conditioner (UPQC), and other related Custom Power Devices [17].
This property of the UPS makes it to always be operating at its full power whereas the DVR injects only the difference between the pre-sag and the sagged

voltage and also only during the sagged period. Therefore, as compared to UPS, DVR required power rating and the operating losses is very low. Thus DVR is seen as a power-efficient device compared to the UPS [18]. Among custom power devices, the DVR provides the most economical solution in overcoming the voltage-related PQ problems [19]. The possible area to improve upon is sag/swell Detection Time (DT) because it is the most important aspect of sag/swell mitigation. In order to achieve this, a very fast detection technique: GIFL technique will be employed. With this proposal, it is expected that at the end of this research, the performance of DVR will be enhanced in terms of overshoot and sag/swell detection time.

II. METHODOLOGY

The methodology employed in achieving the aim of the work is described as follows:

a) Modelling of peak value evaluation in MATLAB Simulink

The peak value detection is used in this research to instantly detect the voltage magnitude change during transient. Figure 1 shows the process involved in detecting the peak value. Measurement of the single phase line to neutral voltage is first done after-which the 90º phase shifter is used in determining the cosine value of the voltage. The two voltages are squared and sum as seen in Figure 1 to obtain the root mean square voltage whose square root gives the peak value of the detected voltage.

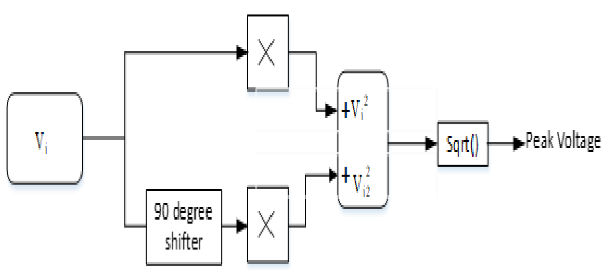


Figure 1: Process of Detecting Peak Voltage

The equation for the input voltage (V_i) is represented as:

vi (t) = Vmsin(wt) (1)

Where V_m depicts the peak value of the input voltage. If v_i (t) is sent to a 90º phase shift circuit, then v_{i2} (t) is obtained as:

$$v_{i2}(t) = V_m \sin\left(wt + 90^o\right)$$ (2)

Which can also be represented as:

$$v_{i2}{}'(t) = V_m \cos\left(wt\right)$$ (3)

By taking the square root of the sum of the square; equations (1) and (2) will easily yield the peak voltage.

b) Harmonisation of the GIFL Model with the Peak Value Evaluation Model

The harmonization of the GIFL model with the peak value is done by incorporating the DVR components (VSC, Storage unit and filter circuit) into the peak value. These components are modelled as seen in Figure 2.

c) Modelling of the Voltage source converter

The voltage source converter (VSC) is regarded as the main building block for a DVR. Hence it is important to select the best topology suited for its application to ensure improved system performance. The converter topology employed in this research is the transformer connected voltage source converters. The VSC employed is equipped with fully controllable switches. The IGBT is selected because it is easy to control and well suited for the actual power range. The DVR topology is illustrated as seen in Figure 2 with injection transformer and LC filter. The DVR is based on 1200 V IGBT modules with rated DC link voltage of 560 V. The carrier based sine modulation and amplitude modulation is represented as:

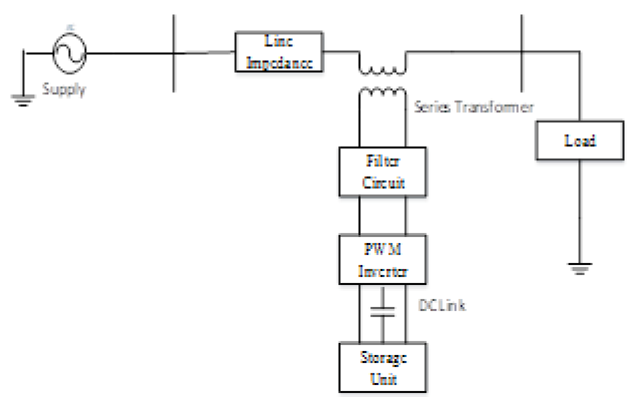


Figure 2: Block Diagram of the DVR Scheme

$$m_a = \frac{\hat{u}_{conv}}{\hat{u}_{tri}}$$ (4)

$$\hat{u}_{tri} = U_{DC} \quad (5)$$

The work developed used a substation to feed the sensitive load. The voltage sag or swell can be generated in the system by creating a fault. The DVR system is connected to the distribution system via the injection transformer. The system comprises of four (4) subsystems as explained earlier. The VSC unit is responsible for converting the DC voltage to AC voltage using the switching topology of IGBT. While the filter units helps minimize the dominant harmonics generated by the inverter circuit.

Two operating modes (stand by and operating) are analyzed on two different scenarios in the work to ensure the efficacy of the developed scheme.

d) Injection Transformer

The DVR is configured to operate with single phase transformer and the VSC to generate zero sequence voltages. The transformer ratio is sized based on the capability of the VSC and the injection level of it into the system. The injection transformer helps in injecting the needed voltage into the system at the load bus. Parameters needed to ensure proper integration of the transformer into the DVR are the current and voltage primary winding ratings, the MVA rating, the values for the short circuit impedance of the transformer and the turns ratio.

III. RESULTS AND DISCUSSIONS

The performance of the developed scheme in effectively minimizing voltage sag/ swell is tested and evaluated using Matlab Simulink in this section. Three different scenarios were modelled and simulated.

Result for Scenario 1

In this scenario, a voltage dip was generated on the system by reducing the supply voltage. The simulation time is 1 seconds.

Figure 3 shows the results of the system supply voltage experiencing voltage sag. The voltage in the system was decreased to fifty per cent (50%) of its normal value for a duration of 0.3 seconds between times 0.2 seconds to 0.5 seconds. The red plot represents the peak values of the detected voltage. It was observed that the peak detection technique employed ensured that the sag in the system was quickly detected.

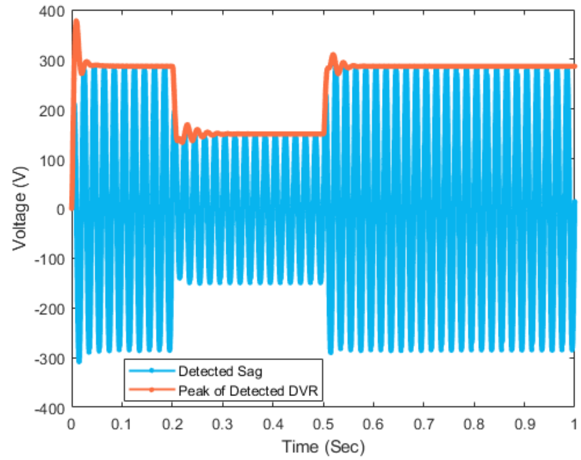


Figure 3: Voltage Sag Waveform Before Mitigation

Figure 4 shows the measured plot of the system voltage and the response of the developed DVR and the standard DVR to the occurrence of voltage sag. From the plot, it is observed that at time 0.2 seconds when the sag was experienced in the system, the DVR switches from standby operation to injecting active voltage to the system. The DVR was then able to clear the dip at time 0.5 seconds when the voltage is back to the pre-sag voltage.

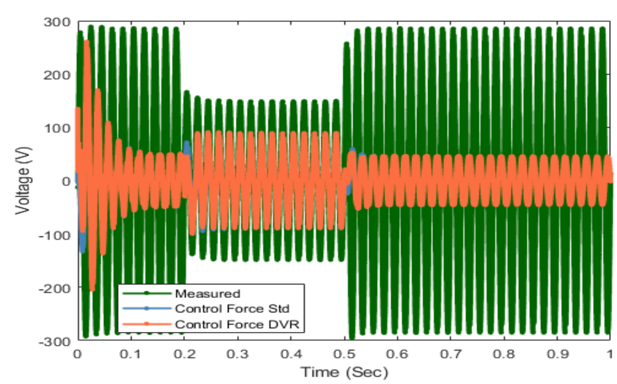


Figure 4: Response of DVR Scheme to Voltage Sag

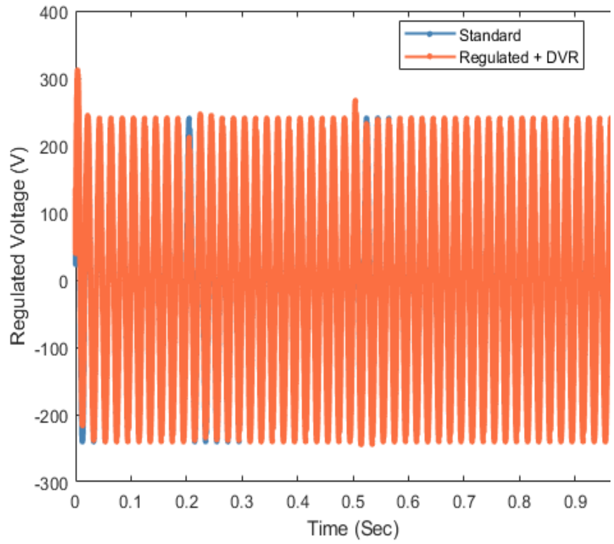
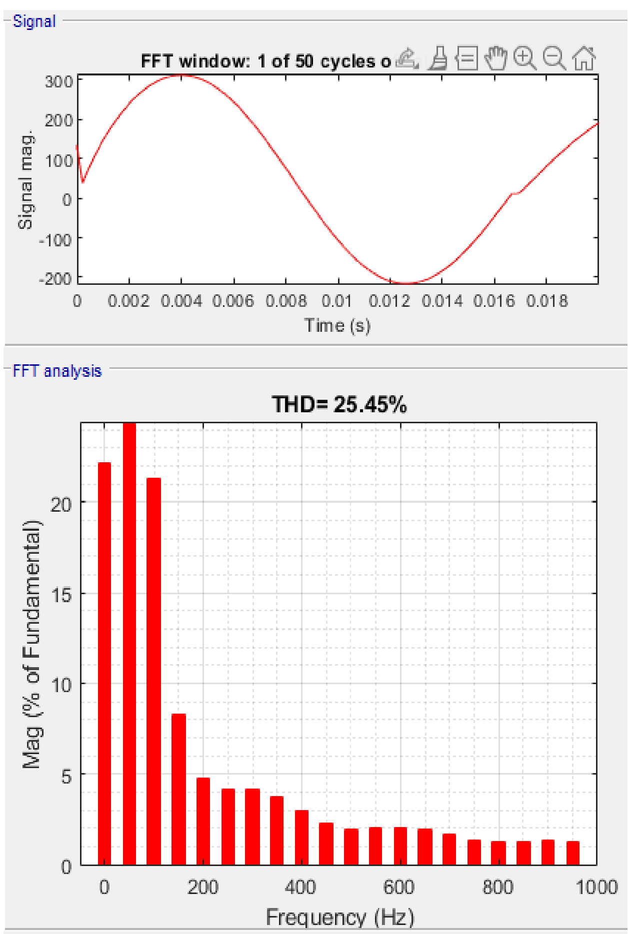


Figure 5: Load Voltage after Compensation

Figure 5 shows the voltage sag waveform after mitigation of the sag introduced (load voltage).



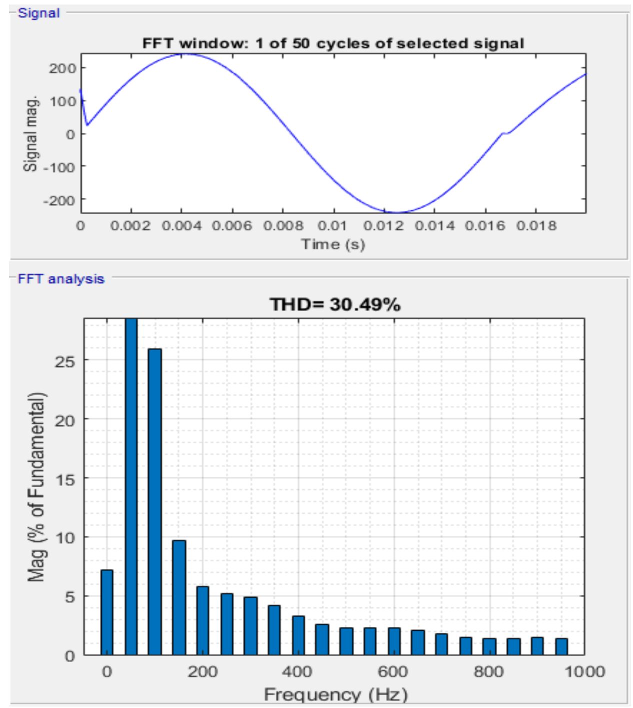


Figure 6a and b: FFT for the Modified DVR and the Standard DVR

Figure 6a shows the FFT analysis of the system when the modified DVR was incorporated. The figure shows how the total harmonic distortion (THD) was minimized due to the implementation of the DVR. It was observed from the results that the THD value for the system is 25.45% during the fault.

Figure 6b shows the FFT analysis of the system when standard DVR was incorporated. The figure shows how the THD was minimized due to the implementation of the DVR. It was observed from the results that the THD value for the system is 30.48% during the fault.

RESULTS FOR SCENARIO TWO

Figure 7 shows the voltage supply of the system. Voltage swell was created in the system between time 0.4 – 0.5 seconds. The voltage swell introduced represents 150% of the total system voltage (150 V).

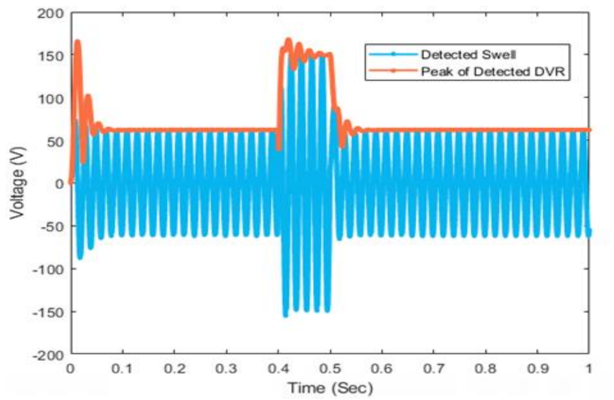


Figure 7: Voltage Swell Waveform Before Mitigation

Figure 8 shows the measured voltage and the response of the DVR to the system in the occurrence of voltage swell. It is observed from the figure that the DVR was able to switch to operating mode at 0.4 seconds when voltage swell was incorporated into the system as such, the DVR was able to clear the swell at time 0.6 seconds.

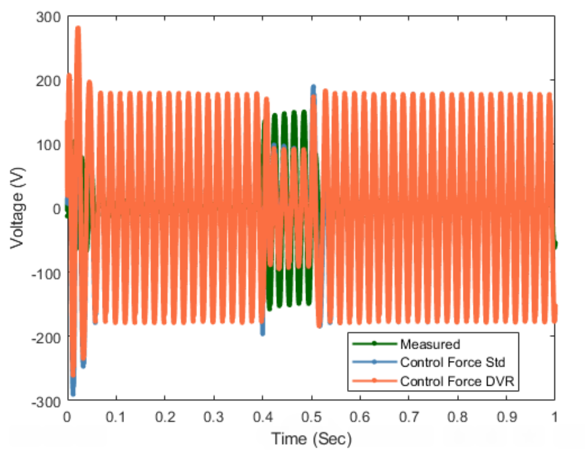


Figure 8: Response of DVR Scheme to Voltage Swell

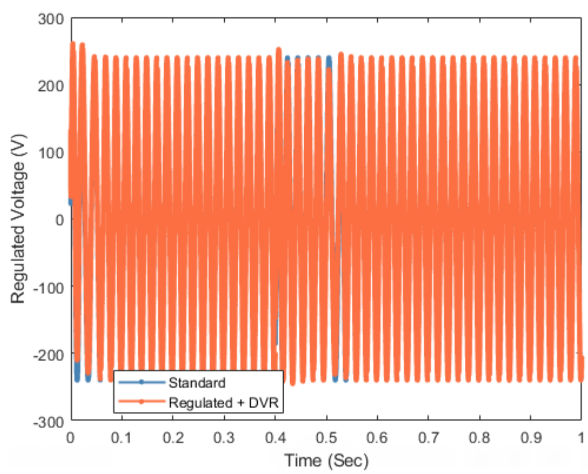


Figure 9: System Load Voltage after Compensation

Figure 10 shows the FFT analysis of the system when the modified DVR was incorporated to minimize the voltage swell in the system. The figure shows how the THD was minimized due to the implementation of the DVR. It was observed from the results that the THD value for the system is 1.24% during the fault.

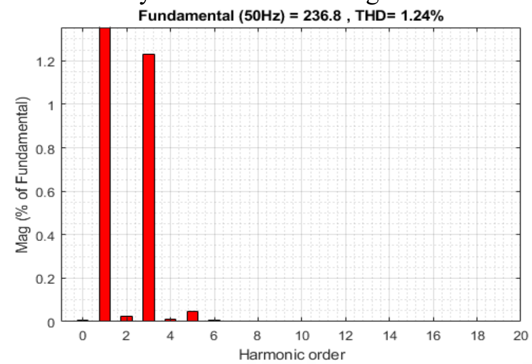


Figure 10: THD value for the Compensated Load Voltage using Modified DVR

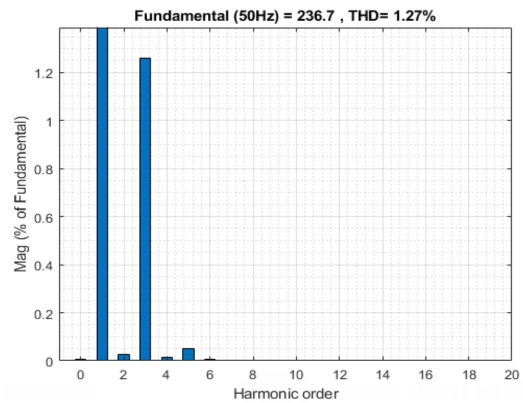


Figure 11: THD value for the Compensated Load Voltage Standard DVR

Figure 11 shows the FFT analysis of the system when the standard DVR was incorporated to reduce the voltage swell in the system. The figure shows how the THD was minimized due to the implementation of the DVR. It was observed from the results that the THD value for the system is 1.27% during the fault.

Result of Scenario Three

Figure 12 shows the voltage source of the distribution system experiencing both voltage sag and swell. It was observed from the figure that the sag was introduced at time 0.18 second and cleared at time 0.25 seconds. Voltage swell was also introduced into the system at time 0.3 seconds to 0.42 seconds.

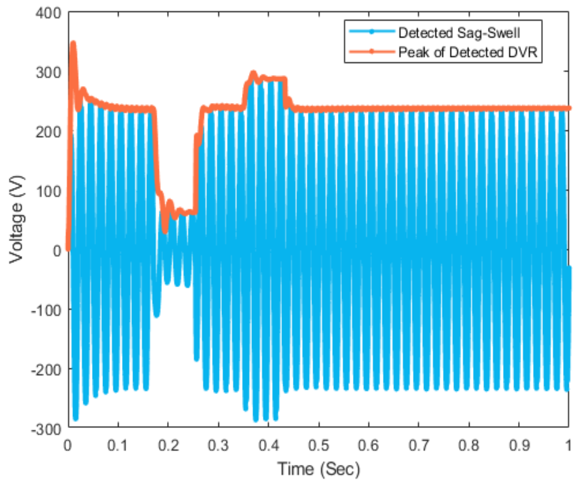


Figure 12: Voltage Source with Presence of Sag and Swell

Figure 13 shows the measured voltage and the response of the DVR to the system in the occurrence of voltage sag and swell. The result shows that the DVR was able to switch to operating mode at 0.18 seconds during the occurrence of sag to inject needed voltage to the system, after-which the DVR switched back to standby mode at time 0.22 seconds when the sag has been cleared. The DVR was able to also detect the swell in the system at time 0.35 seconds and the voltage in the system was reduced.

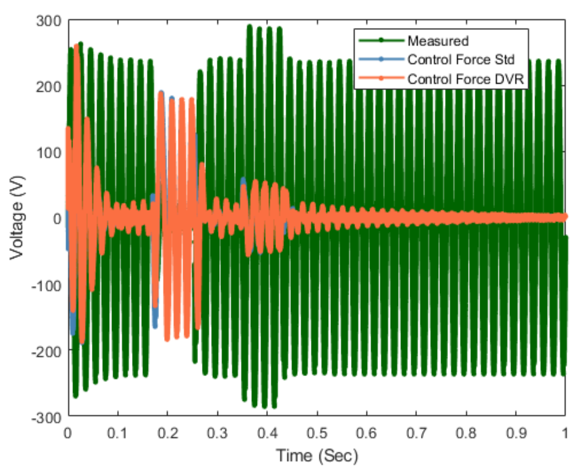


Figure 13: Voltage injected by standard DVR and Modified DVR

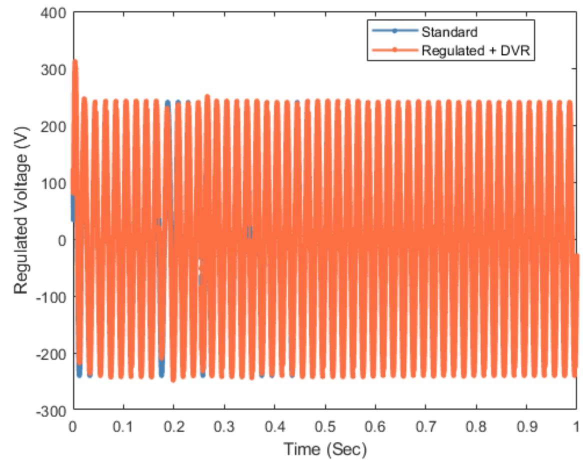


Figure 14: Load Voltage of the System

Figure 14 showed the load voltage of the system which represents a sag and swell free corrected system voltage for both the standard DVR and the modified DVR. It was observed that the load voltage obtained when the modified DVR system was used is pure with less unwanted frequency elements.

IV. CONCLUSION

The power quality disturbances are voltage sag, swell, notch, spike and transients etc. The voltage sag and swell are most important problems for an industrial customer which needs urgent attention for its compensation. In this research work, the development of dynamic voltage restorer based on GIFL technique for fast voltage sag/swell detection and mitigation is presented. A GIFL technique scheme was developed and incorporated into the DVR. The developed scheme was implemented on MATLAB/ Simulink and the results obtained presented using THD as performance metrics. The system was divided into three scenarios (system with voltage sag and system with voltage swell). The result obtained for the first scenario when only sag was introduced in the system showed that the developed scheme was able to compensate for the sag with a THD value of 25.45% while THD value of 1.24% was obtained for the system having only voltage swell as the disturbance. To ascertain the effectiveness of the system developed, the results obtained were compared with those obtained when the conventional DVR system was used for mitigating the faults. When voltage sag was introduced into the system, the THD value obtained for the developed scheme outperformed that obtained from the conventional DVR by 19.81% while a percentage improvement of 2.3% was obtained when only voltage swell was incorporated into the system.

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