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Enhancing Power Quality using a Dynamic Voltage Restorer (DVR) with PI Controller

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Abstract: Nowadays, many people are shifting and adapting to the renewable energy sources like wind and solar which are free of cost and easily available to us. But shifting to the renewable energy sources comes with some problems, and we need to focus on those problems. So the power quality is the main problem in this power system and maintaining it consistently time to time. Some situations like voltage sags, voltage swells, harmonic content and so on has major effect on load side. To overcome this problems custom power devices like Dynamic Voltage Restorer(DVR), Distribution Static Compensator are used in power distribution networks. From this custom devices I picked the Dynamic Voltage Restorer(DVR) for my project. The Dynamic Voltage Restorer has much quality like fast flexible and efficient solutions to the voltage sag and swell problems. The DVR works by injecting the voltage in series and synchronize with the standard voltage ensuring a stable power supply. It continuously monitors the standard voltage and if any deviations occur it quickly injects are decreases the voltage keeping the power supply stable. The important parts of the DVR are voltage source inverter(VSI), boost transformer, filter and DC energy source (Solar energy, Wind energy, Battery).This DVR has an excellent performance in protecting the critical load from voltage sag and swell problems.So that's why I am going with this custom device. By using this I will compensate the voltage fluctuations and instability in the power distribution networks.

Keywords: Dynamic Voltage Restorer(DVR),Voltage Source Inverter(VSI), Sag, Swell, Harmonic,Three Line to Ground Fault(TLGF).

I. INTRODUCTION

The power system network should give stable and uninterrupted power supply to the customers with a pure sinusoidal voltage. The Power system has number of loads which are nonlinear that causes the deviations and affects the power quality in power supply. As a result of nonlinear loads, the purity of the sin wave in power supply will be lost. Apart from the nonlinear loads the capacitor switching ,motor starting and unusual faults creates power quality problems in the power system networks. The power quality issue is defined as a deviation of voltage and current from its stable waveform. Faults happened at either while sending end side or receiving end side causes voltage sad and voltage swell in the whole power system. Voltage sag and voltage swell will damages and creates large current unbalance in the sensitive equipment.There are many techniques and methods to mitigate this voltage sag and voltage swell problems but use of custom power devices is the best and efficient method. The word custom power means use of power electronics controller in distribution system. Custom power devices will make sure the customer to get presatisfied quality and reliability of supply. There are many types of custom power devices available to mitigate power quality problems. But compared to other DVR is the best and economic solution for this problem.To get the maximum output voltage from three phase inverter there is need to reduce switching looses of inverter. This can be achieved by selecting proper switching patterns for inverter. To fulfill this requirement PWM technique can be used.

PROBLEM STATEMENT AND PROBLEM DEFINATION:

The power quality issues will create very big problems for the load. So to protect the devices from damaging we need to use custom power devices. From different types of custom power devices, the DVR is the most economic and efficient one and best option. But DVR has switching losses and harmonic distortion from the inverter which create issues with the DVR output voltage.The Switching losses and THD of inverter need to be reduced. As shown in following equation we have to reduce the value of total harmonic distortion.

$$THD_F = \frac{\sqrt{V_2^2 + V_3^2 + V_4^2 + \dots\dots}}{V_1} \quad \text{…………..(1)}$$

II. LITERATURE REVIEW

The Dynamic Voltage Restorer(DVR) is a broadly utilized control quality enhancement custom power device planned to ease voltage sags, swells, and other harmonic disturbances in electrical conveyance frameworks. Among the DVR the control procedures like Proportional-Integral(PI) controller is one of the foremost for the most part upheld due to its straightforwardness, ease of tuning, and viability in keeping up voltage steadiness. Bollen(2000) bandied the portion of PI controllers in DVR operations, squeezing their capability to reestablish voltage preoccupations successfully. Kumar and Ghosh(2007) upheld a PI- grounded DVR and illustrated its adequacy in compensating voltage droops; still, they famous that the settled pick up settings of the PI controller redounded in slower reaction times beneath fleetly changing conditions. Mishra et al.(2012) compared PI control with other progressed control ways comparable as fluffy sense and set up that whereas PI controllers grant steady and reliable operation, their execution can be caustic in to a great extent energetic environment due to the require for exact tuning. New investigation by Ghassemi et al.(2014) proposed that optimization ways, comparative as inheritable calculations or flyspeck mass optimization, can be utilized to fine- tune PI controller parameters, culminating their inflexibility to changing lattice conditions. In spite of these headways, PI- controlled DVRs still parade confinements in taking care of nonlinear loads and unsteady faults. Overall, PI controllers stay a favored choice for DVRs due to their direct plan and execution, but their stationary nature postures challenges in energetic control framework conditions, egging the disquisition of versatile and intelligent control techniques for bettered execution.

III. DYNAMIC VOLTAGE RESTORER

Most electric power systems utilize DVR as a specialized custom device. The main use of DVR is it serves to minimize voltage sag problems and protect the sensitive loads. They have been designed to provide compensation for voltage sags up to 35% in duration under half a second. The DVR system connects to the feeder through an injection or coupling transformer. The primary purpose of the DVR system is to load bus voltage regulation while it stays mostly in standby state. The converter operates in bypass mode when the DVR remains idle in standby mode.The DVR initiates series voltage injection after it detects a voltage sag are voltage swell. The DVR with power electronics generates a series voltage of required magnitude to bring back the system to stable condition. The power electronics device of DVR can operate as a series active filter which isolates the load from voltage harmonics present on the source side. The load protection system blocks voltage harmonics coming from the power source. The voltage balance on the load side can be achieved through injection methods. The DVR system can balance load side voltage by injecting negative or zero sequence voltage along with harmonic voltage.

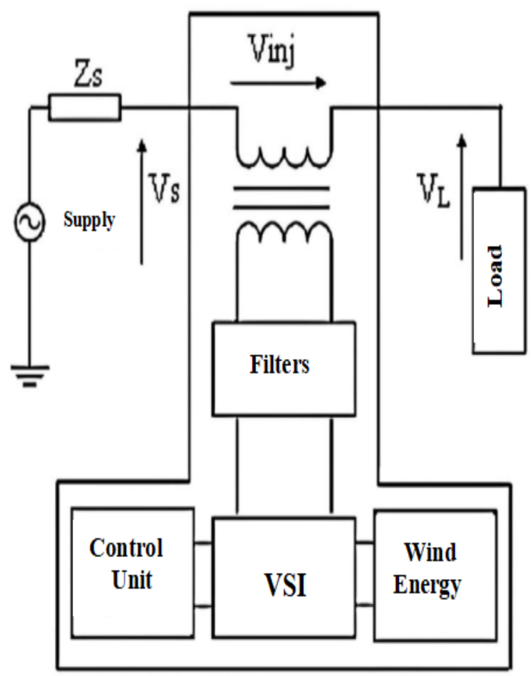

Figure-1: Schematic Representation of DVR

Proportional-Integral(PI) control is a widely used algorithm in the control system of a Dynamic Voltage Restorer(DVR) to insure accurate voltage injections. Under moderate load conditions we can use different control techniques such as Model Predictive Control (MPC) or Fuzzy Logic Control or Artificial Neural Networks (ANN) can be employed to improve performance better. The DVR continuously monitors the load voltage using voltage detectors. When voltage variations in systems are detected, the DVR's control system fleetly calculates the necessary compensating voltage and activates the voltage injection to supply the applicable voltage. This process is appertained to as" reversal." Certain DVR systems incorporate energy storehouse bias, similar as batteries or super capacitors, to increase the needed voltage injection during sags. The integration of DVRs with communication systems in smart grid technology's will allows the transmission of real- time voltage data, enhancing overall system monitoring and operation of the power distribution networks.

IV. CONTROL STRATEGY

A. Block diagram of Voltage sag and swell Mitigation

Figure-2 shows the block diagram of the process for mitigating voltage sag and voltage swell due to TLGF in distribution system. Initially the source will supply to the load in a normal and steady state way. Then, the TLGF will be created with externally in distribution system. According to this problem, a DVR is designed and implemented to compensate the voltage sag and swell problem in the system. Each stage it will be observed through voltage (V) measurement.

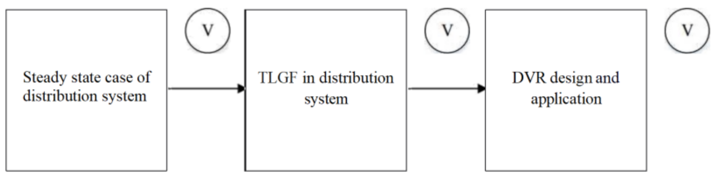

Figure-2: Process of Voltage sag and swell Mitigation

B. Steady state Case

Figure-3 shows the test case circuit configuration of a distribution system in normal and steady state case (i.e. without fault). The source of voltage is set to 11kV for the power system. The transformer will step-down voltage from 11 kV to 400 V. Circuit breaker is used to connect transformer with load consisting of resistor (R) and inductor (L).

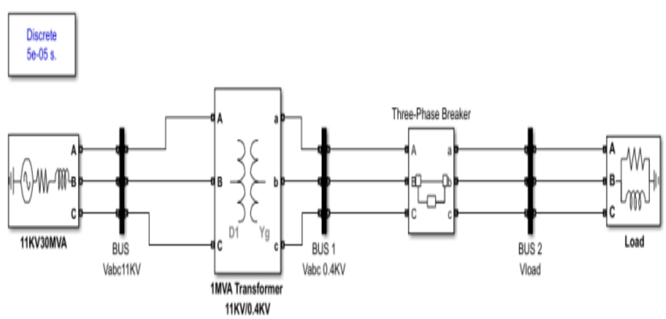

Figure-3: Distribution network in steady state condition

C. TLGF case

Figure-4 shows the TLGF setting while Figure-5 shows the temporary TLGF (in between phase-A phase-B phase-C and ground) in distribution system. The time setting for the fault is 0.1 seconds i.e. 0.1-0.2seconds(swell),0.3-0.4 seconds(sag). The system will automatically return-back to the steady state after the fault time is pass. However, voltage sag and swell will appear during measurement.

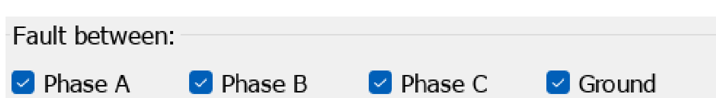

Figure-4: Fault setting for system

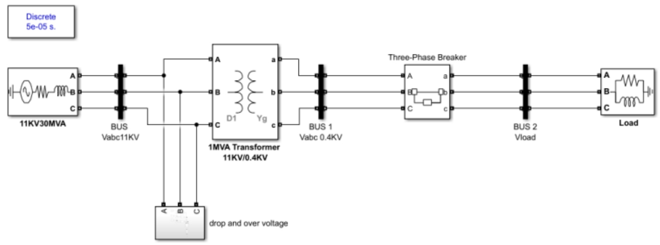

Figure 5: Distribution system in TLGF condition

D. DVR in TLGF Case Causing Voltage Sag and Swell

The DVR will work when voltage sag and swell occurs due to TLGF in the system. It will give signals to the PI controller when the measured voltage is different from the steady state and normal voltage. The control unit generates the voltage reference to input to the modulation unit and generate modulation signal for VSI of DVR. To compensate for the voltage sag and swell, the Wind Energy Source which is connected through DC link injects or absorbs the appropriate voltage. The harmonics in the DVR output is reduced by connecting an output filter between the VSI and the injection transformer. As a result, the VSI pulse-modulated voltage is converted to sinusoidal voltage by the filter. A series injecting transformer injects the corrected voltage into the distribution system. The voltage injection of equal amplitude will be generated by DVR by observing the instant of sag and swell that occur in the system due to TLGF to produce a perfect voltage sag and swell compensation.Figure-6 and Figure-7 shows the distribution system with DVR and connection of DVR. It contains the injection transformer, RL and RC for the filter, VSI i.e., insulated-gate bipolar transistor(IGBT) will be act as a switching device with pulse width modulation (PWM), the Wind Energy Source and the controller for the system. Figure-8 shows the use of PI controller for the system to control the signal when unbalanced condition occurs. The output of the controller will mitigate the voltage sag and swell which is to inject or absorb the voltage for the system. The PWM generator will generate pulses to control the operation of DVR through IGBT and generate pulses form PWM-controlled 2-Level converter, using carrier-based two-level PWM method.

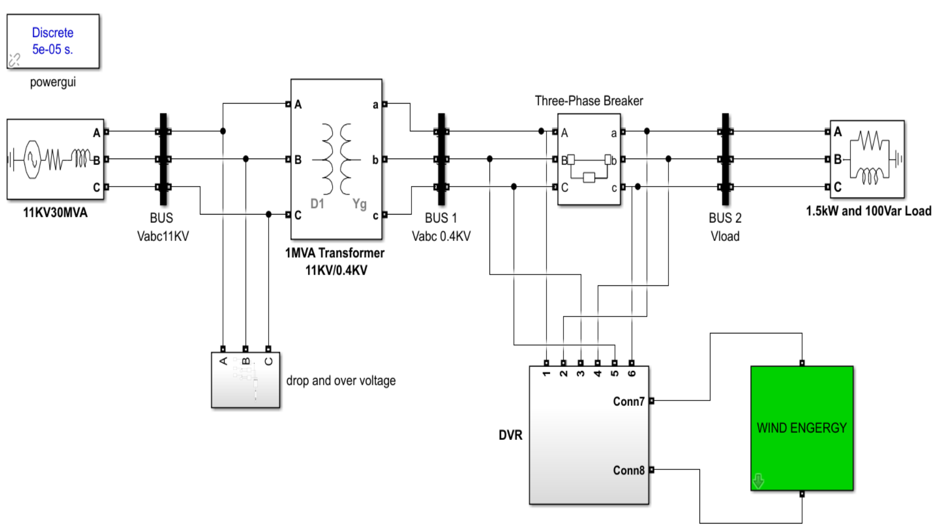

Figure-6: : Distribution system with DVR

A three-phase breaker is connected between Bus 1 (at 0.4 kV) and Bus 2, where a 1.5 kW, 100 VAR load is placed. The breaker allows for isolation and protection during faults or voltage sags. To mitigate issues such as voltage sags, swells, or transient disturbances, a Dynamic Voltage Restorer (DVR) is connected at Bus 1. The DVR monitors the line voltage and injects compensating voltages in series to maintain the voltage profile at the load terminals within acceptable limits. The control strategy for the DVR relies on the measurement of the voltage at Bus 1 and comparison with a reference voltage. Any deviation is processed using a control system—typically based on synchronous reference frame theory (dq0 transformation) as shown in the previous control diagram you shared.

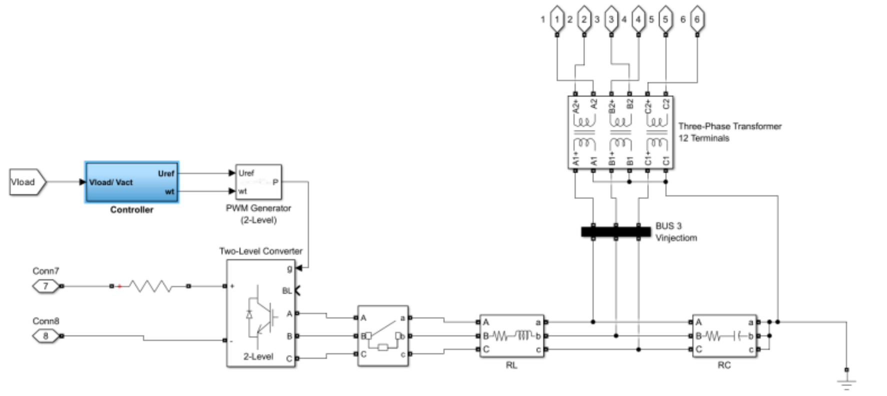

Figure 7: Connection of DVR terminals

In this control system, the three-phase voltage is transformed into a rotating reference frame (dq0) using the angle obtained from a virtual Phase Locked Loop (PLL). The dq components are compared to reference values (usually d_ref = 1 and q_ref = 0), and the error is passed through Proportional-Integral (PI) controllers to generate the corrective dq voltages. These are then transformed back into three-phase abc signals using the inverse Park transformation and fed to the DVR, which injects these voltages in series with the supply to maintain voltage quality.

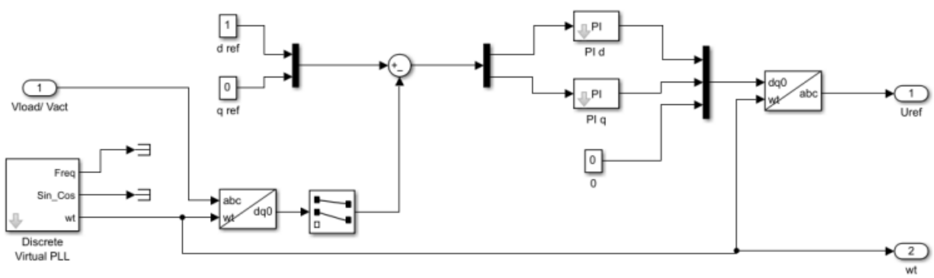

Figure 8: Controller Unit

Additionally, a wind energy source is connected at Bus 2, contributing to the local load and supporting voltage stability. The integration of this renewable energy source helps reduce dependency on the grid and improve system resilience. Together, the system demonstrates how DVR and renewable energy can be effectively combined for smart grid applications, ensuring continuous and high-quality power delivery to sensitive loads even under dynamic conditions.

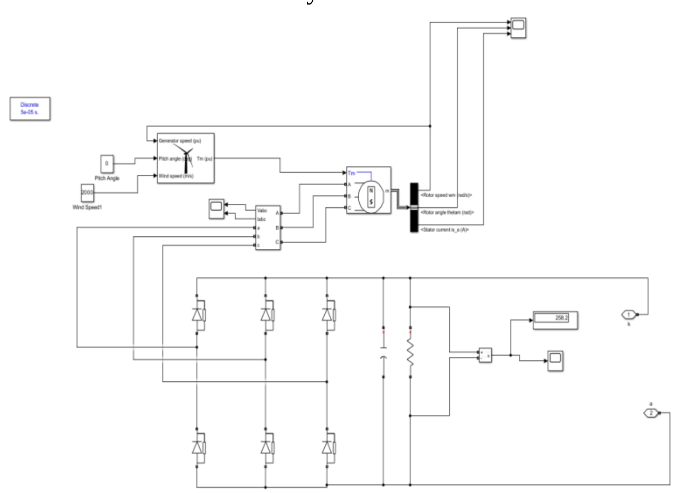

Figure-9: Wind energy generation unit

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V. RESULTS AND DISCUSSION

A. *Steady state case*

Figure-10 shows the simulation results for the steady-state condition illustrate that the voltage waveform remains a pure sinusoidal waveform while maintaining its amplitude at 1 p.u., during the simulation. This indicates that the voltage remains stable throughout the operation, ensuring reliable performance in the control system.

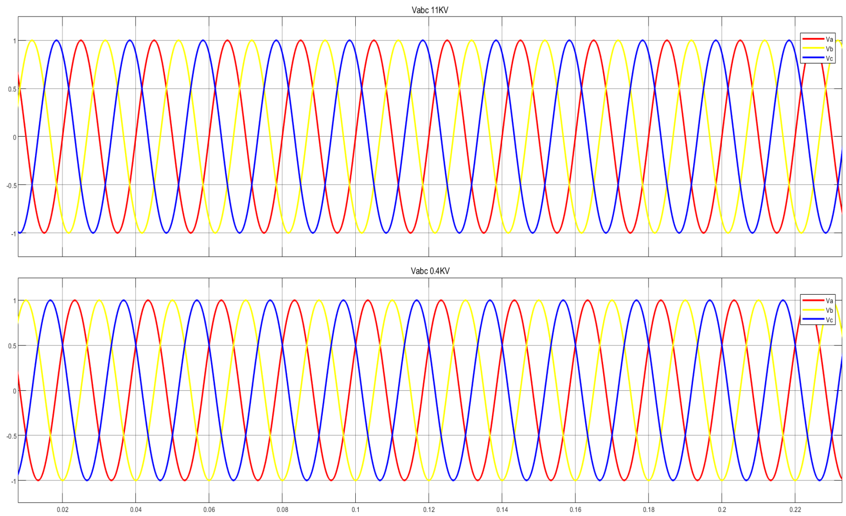

Figure 10: Voltage waveform during steady-state case

B. *TLGF Causing Voltage Sag and Swell Case*

Figure-11a and 11b shows the simulated result of voltage during TLGF case. It shows the voltage in (p.u.) against time when TLGF occurs during 0.1 - 0.2 second and 0.3 - 0.4 second. The voltage waveform drops from 1 p.u. to below 0.5 p.u. and voltage waveform spikes from 1 p.u. to above 1.5 p.u. that supplies the facility according to IEEE 1159 standard, hence it need to be mitigated.

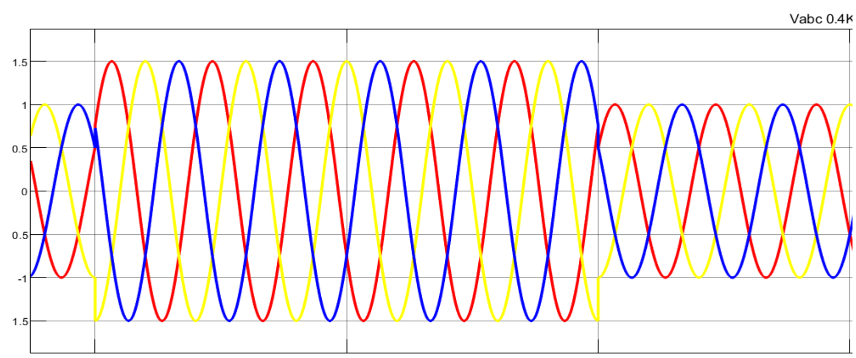

Figure-11a: Voltage swell during TLGF

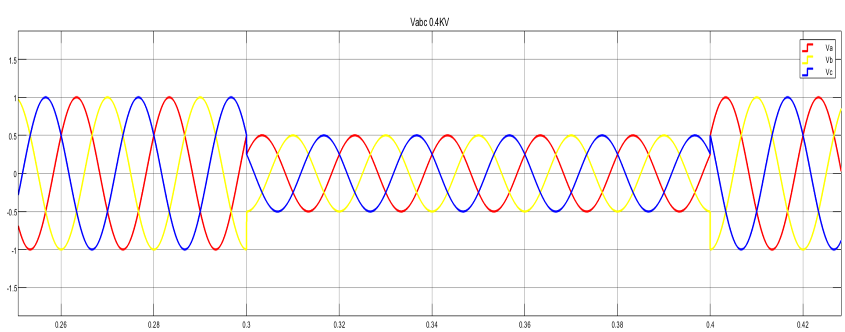

Figure-11b: Voltage sag during TLGF

C. Mitigation of Voltage Sag and Swell with DVR Case

The designed DVR was applied in a TLGF case for mitigation of the Voltage sag and Swell. Figure-12 shows the simulated result of mitigated voltage sag and swell with DVR during the TLGF case. From the waveform it can be seen that there is voltage notching of magnitude of -1 to -1.5 p.u. after 0.1 second. This is because of switching circuit in the DVR. Figure-13 shows the voltage injection from DVR. The voltage injection of equal amplitude will be produced by DVR by monitoring the instant of sag and swell that occurred in the system due to TLGF to produce a perfect voltage sag and swell compensation in the system.

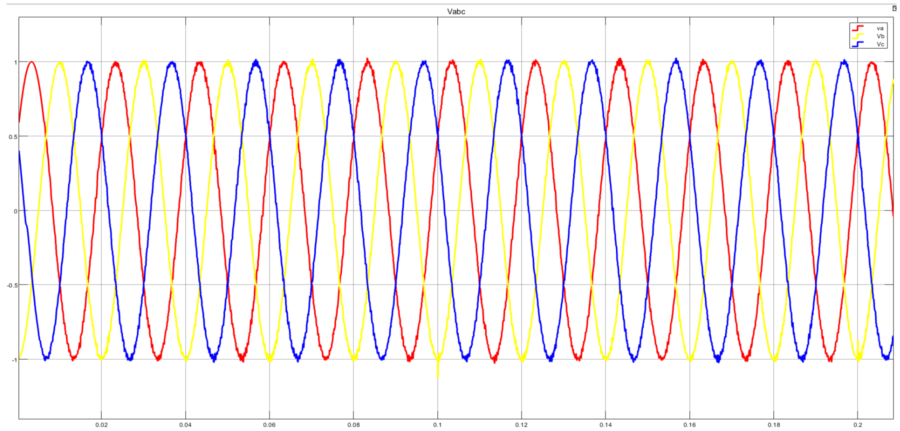

Figure-12: Mitigated voltage sag and swell waveform with DVR during TLGF case

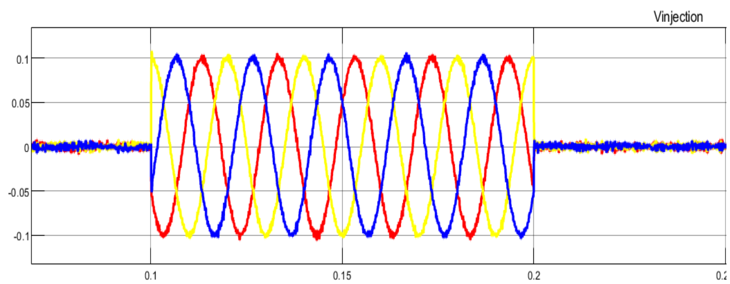

Figure-13: Voltage injection from DVR

From figure-14 we can see the before and after the voltage sag and swell compensation with the DVR in the system and how the DVR injected the voltage only during the fault period.

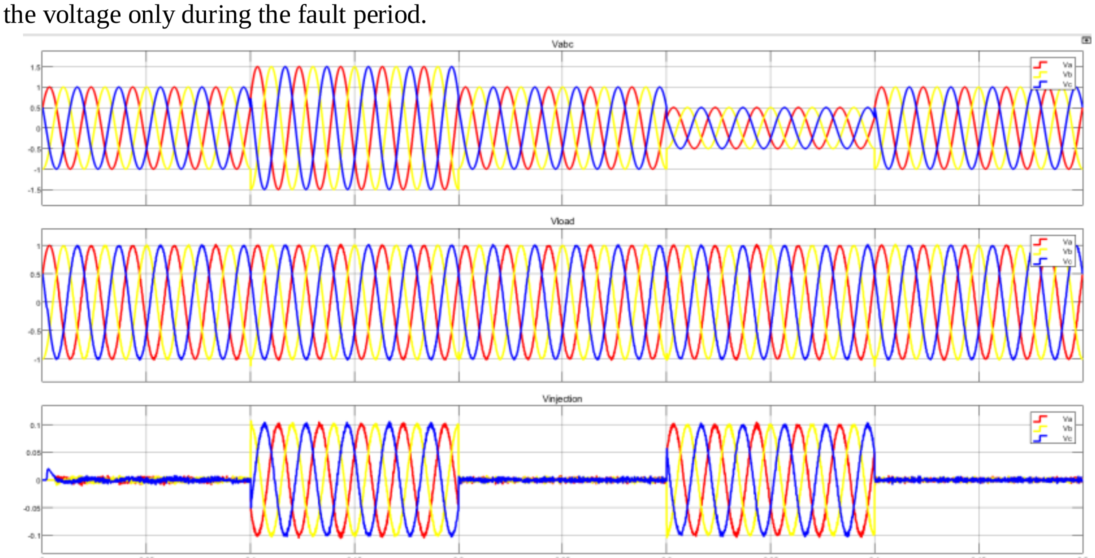

Figure-14: Before and After the voltage sag , swell and Voltage injection on the Load side.

TABLE I
THD BEFORE AND AFTER VOLTAGE SAG MITIGATION FOR A THREE-PHASE FAULT

Before injection (pu)			Mitigation by DVR Park's Transformation (pu)		
A	B	C	A	B	C
0.6795	0.6793	0.6787	0.9867	0.9887	0.9775

TABLE III
THD BEFORE AND AFTER VOLTAGE SAG MITIGATION FOR A THREE-PHASE FAULT

Mitigation Technique	THD before mitigation (%)	THD after mitigation (%)
DVR Park's Transformation	23.60	1.93

VI. CONCLUSIONS

In conclusion, the objectives of this project to design DVR for compensating voltage sag and swell caused by TLGF are achieved. The performance of DVR in distribution system against voltage sag and swell has been developed by using MATLAB/Simulink (2024b). Also TLGF is considered in distribution line. The problem of voltage sag and swell has been determined by referred in three cases which is steady state, TLGF case and its mitigation with DVR. The outcome
show that all result are obtained successfully based on the three cases.

VII. ACKNOWLEDGMENT

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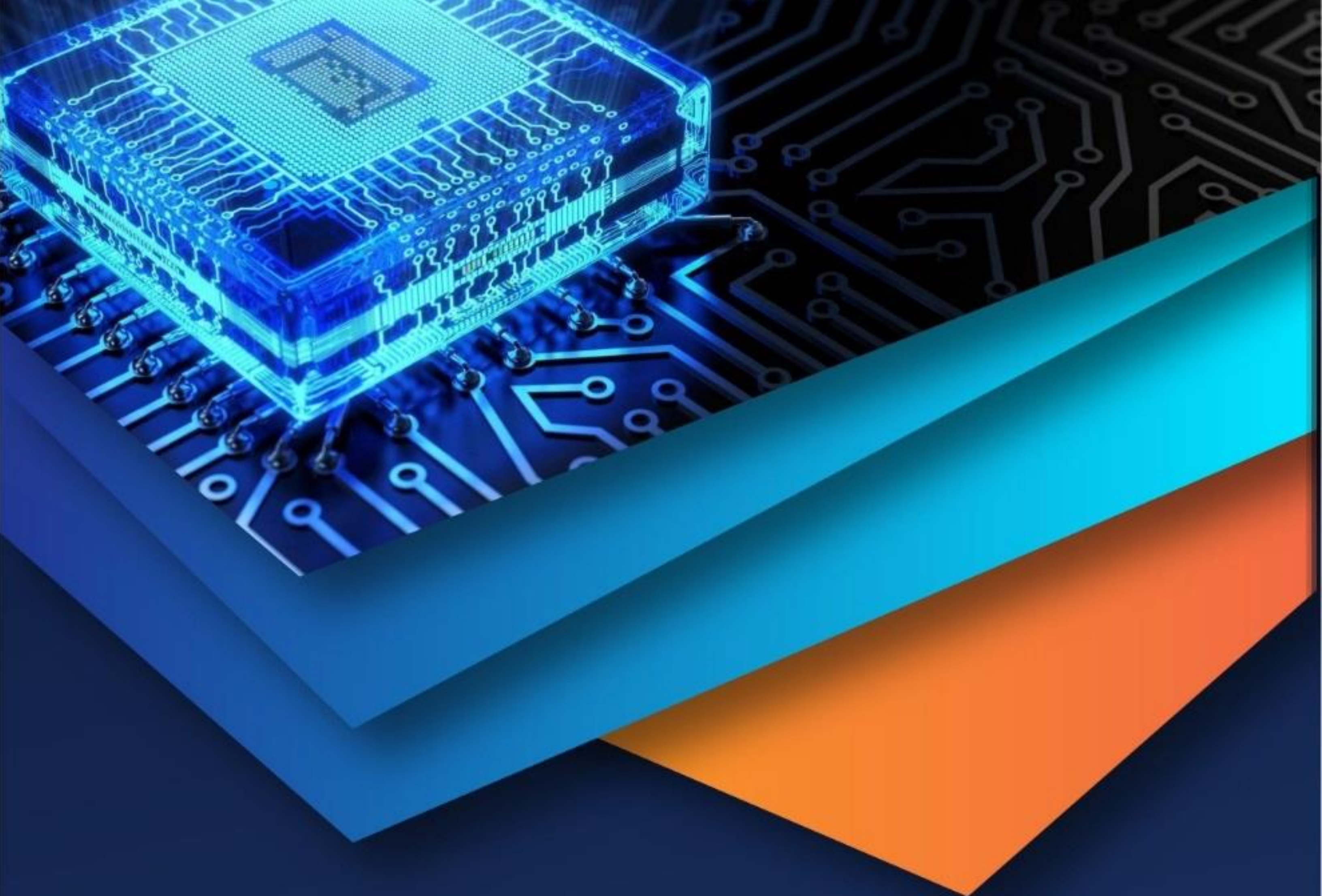
[9] Mitigation of Voltage Sag Caused by Single Line to Ground Fault in Distribution System by using Dynamic Voltage Restorer in Matlab/Simulink Muhammad Afiq Mohamad Rosli1, Dur Muhammad Soomro1* Faculty of Electrical & Electronic Engineering, Universiti Tun Hussein Onn Malaysia, Parit Raja, Batu Pahat, 86400, MALAYSIA DOI: https://doi.org/10.30880/eeee.2021.02.02.061



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