Improving Voltage in the Presence of Distributed Generation Using the Dynamic Distributed Voltage Regulator (DDVR)

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Abstract

Improving the electrical voltage in distribution networks during the occurrence of disturbances leads to solving one of the problems of electrical power quality. The presence of sophisticated power electron elements helped alleviate power quality problems, Therefore, the use of a Distributed Dynamic Voltage Regulator (DDVR) provides the most economical solution for improving Voltage disturbances by injecting voltage into the system compared to commonly used compensators.

This study proposes the use of a DDVR to improve voltage disturbances in distribution networks. The study conducted modeling of a DDVR with a Voltage Source Converter - VSC in a MATLAB/Simulink environment in the presence of a distributed solar PV generation source.

The results of the study showed cases of voltage disturbances (droop, bulge, interruption), and how the load voltage waveform was significantly improved whether the disturbances were symmetrical or asymmetrical. The study also demonstrated the good environmental impact of introducing distributed generation and the extent of its reduction in CO2 emissions.

Keywords: Distribution networks, Distributed Generation (DG), Distributed Dynamic Voltage Restorer (DDVR), Voltage disturbances, the environmental impact.

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تحسين التوتر الكهربائي بوجود التوليد الموزع باستخدام معوض الجهد الديناميكي الموزع DDVR

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الملخص:

إن تحسين التوتر الكهربائي في شبكات التوزيع أثناء حدوث الاضطرابات يؤدي إلى حل إحدى مشاكل جودة الطاقة الكهربائية. ساعد وجود عناصر الكترونيات القدرة المتطورة في التخفيف من مشاكل جودة الطاقة، وبالتالي فإن استخدام منظم التوتر الديناميكي الموزع، يؤمن هذا المنظم أكثر الحلول الاقتصادية لتحسين اضطرابات الجهد الكهربائي عن طريق حقن التوتر في النظام مقارنةً مع المعوضات شائعة الاستخدام.

تقترح هذه الدراسة استخدام منظم التوتر الديناميكي الموزع لتحسين الاضطرابات بالجهد الكهربائي في شبكات التوزيع، أجرت الدراسة نمذجة لمعوض التوتر الديناميكي الموزع مع مبدل منبع جهد Voltage Source Converter-VSC في بيئة الماتلاب MATLAB/Simulink بوجود مصدر توليد موزع شمسي PV.

بينت نتائج الدراسة حالات اضطرابات الجهد (تدلي، انتفاخ، انقطاع)، وكيف تم تحسين شكل موجة توتر الحمل بشكل كبير سواء كانت الاضطرابات متناظرة أو غير متناظرة. كما وضحت الدراسة الأثر البيئي الجيد عند إدخال التوليد الموزع ومقدار تخفيضه لانبعاثات غاز CO_2.

الكلمات المفتاحية: شبكات التوزيع، التوليد الموزع، معوض الجهد الديناميكي الموزع، اضطرابات الجهد، الأثر البيئي.

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Introduction:

The Loads voltage source is susceptible to various disturbances, which impact connected loads within the network. These disturbances can cause voltage sags or voltage swells; this will negatively affect other grid connected loads. Voltage asymmetry is resulted from unbalanced phase loading; it is a common issue in distribution networks. Power quality problems related to voltage (sags, swells, interruptions, etc.) is one off the most disturbance, which have a considerable impact on consumers.

To overcome this problem, Distributed Dynamic Voltage Restorers (DDVR) could be used. A DDVR is connected in series between the load and the source through coupling transformers. It injects voltage at the Point of Common Coupling (PCC) to improve the supply voltage waveform and address voltage-related disturbances.

1.Previous Studies:

Voltage is defined as a decrease in the effective value (RMS) of voltage at some point from the network to value between 0.1 [pu] and the value of 0.9 [pu] under nominal frequency during a time ranging half a cycle and 1 min at the binding point of the pregnancy, or the distributed generator. This decline in the value of the voltage represents most of the electric energy quality problems. That are studied in this field (Eltamaly et al.,2018,61).

Poor power quality can lead to power outages, causing damage to circuit breakers, and thus damaging sensitive equipment such as electronic devices and control systems in production lines.

This leads to increased installation expenses losses, which leads to incurring large expenses and stopping the production line. (Meena et al.,2017,1363).

Voltage disturbances (sag and swell) are considered one of the main causes of poor quality of electrical supply due to their frequent occurrence in electrical supply networks (Munoz ,2007,277) ;(Bollen,2000,8).

Voltage disturbances (sag and swell) due to the power supply have been defined during the period of high power demand and operation of large loads such as large motors and transformers (Katole et al.,2017,717).

Several methods are employed to address voltage sag issues, such as using static capacitors to improve voltage quality and compensate for reactive power in the network. Inductive reactors are also employed to consume reactive power in the network during periods of low load. Additionally, Thyristor Switched Capacitors (TSC) and Thyristor Controlled Reactors (TCR) have been used, as well as Static VAR Compensators (SVCs), providing greater flexibility in reactive power compensation control. To mitigate harmonics, passive filters have been utilized (Schipman et al.,2010,10).

However, these traditional methods suffer from various drawbacks, including their substantial physical size, the possibility of resonance, and, most importantly, their fixed compensation, which limits their effectiveness in performing their functions.

2. Impact of Distributed Generation (DG) Integration:

The integration of distributed electrical generation into distribution networks carries both positive and negative technical effects. DG allows control over active and reactive power flows in the network, contributing to voltage regulation (سـاميز، 2018،223).

However, The large penetration rate of distributed generators in the distribution network is one of the main problems that causes the voltage level of the supply connected to the generator to. rise above the permissible limits. This research employs

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DDVR to compensate for voltage network interruptions, ensuring the quality of voltage sources. The study will focus on utilizing DDRV to regulate the voltage, when the system has distributed generation.

It should be mentioned to the environmental impact of distributed generation, like as photovoltaic generation with the capacity of 6608 watts and a voltage of 889 volts, which in turn leads to reducing polluted emissions of the environment, the most important of which is the low CO2 gas emissions.

3. Distributed Dynamic Voltage Restorer (DDVR):

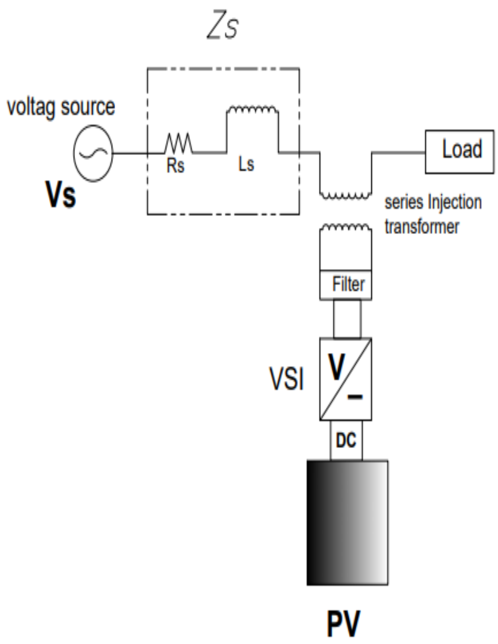

Figure (1) A plan of the (DDVR)

The Distributed Dynamic Voltage Restorer (DDVR) is a series device used to improve electrical voltage and power quality in electrical distribution networks. It is one of the devices that belong to the family of flexible alternating current transmission systems (FACTS) and has become commonly used as an effective solution to protect sensitive loads from voltage disturbances (sag and swell), due to its advantages, especially in terms of cost. DDVR is an electronic device used to inject the voltage and frequency to be compensated. The compensation capacity of the DDVR depends on the maximum real and reactive power should be injected, (stored in capacity). The main function of the device is to regulate the voltage across the load by injecting additional voltage into the transmission system. The location of the dynamic distributed voltage compensator is generally located at the distribution side, i.e. between the distribution feeder and the load.

The structure of the DDVR comprises injection transformers serially connected between the load and the source, serial smoothing reactors, and a Voltage Source Converter (VSC) connected to a DC link (capacitor or DC source). Wind and solar Distributed Generation (DG) are integrated into the distribution network to provide a DC voltage source for compensating interruptions that might occur in the network. The capacitor alone cannot effectively compensate for interruptions, as depicted in Figure (1).

The relationship of the compensated voltage of the Distributed Dynamic Voltage Restorer (DDVR):

$V_{DDVR} = V_{load} + Z_s I_{line} - V_s$ ..(1)

Where:

V_{DDVR}: Compensated voltage by DDVR

V_{load}: Desired load voltage

V_s: Source voltage

Z_s: Transmission line impedance

I_{line}: Line current

5.DDVR operation:

The DDVR unit can be operated in three cases:

1. The first case: protection status.
2. The second case: Standby status..
3. The third case: the state of the injection (Munoz ,2007,217); (Dugan et al.,2006,71).

5-1. Protection status:

In the case of protection, the switching circuit breaker is located between the DDVR and the power system so that the compensation is protected when a short circuit occurs from the pregnancy side. Figure (2) explains the state of protection.

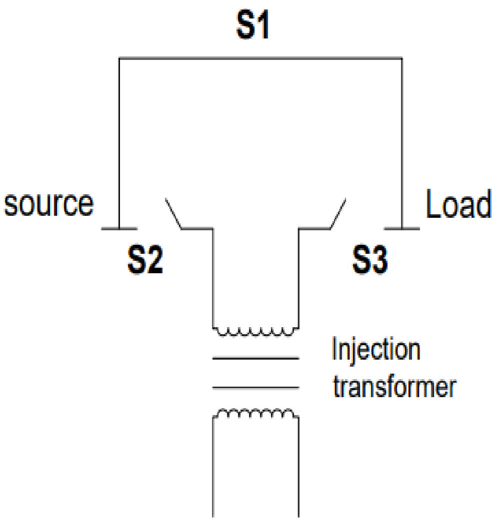

Figure (2) protection state

5-2. Standby state ($V_{DDVR} = 0$):

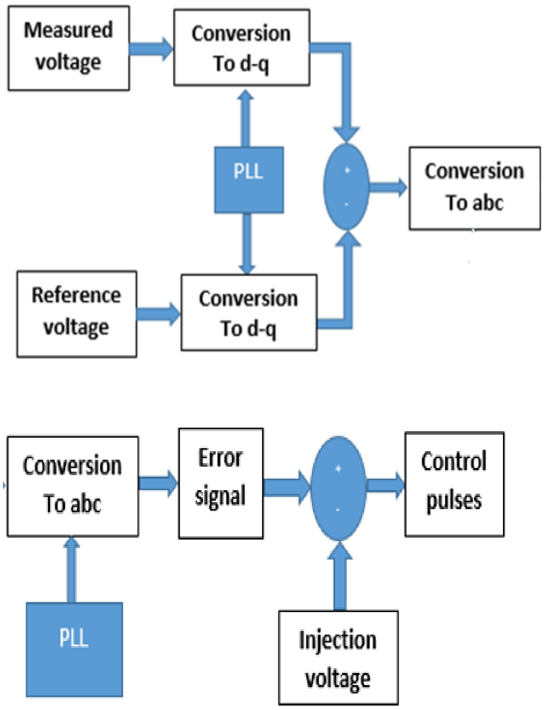

Figure (3) readiness state

In the case of the DDVR voltage is equal to the source voltage, and therefore the feeding of the compensation will not take place and the load current will pass through the first winding of the injection adapter and the secondary winding are limited. Figure (3) explains the standby state

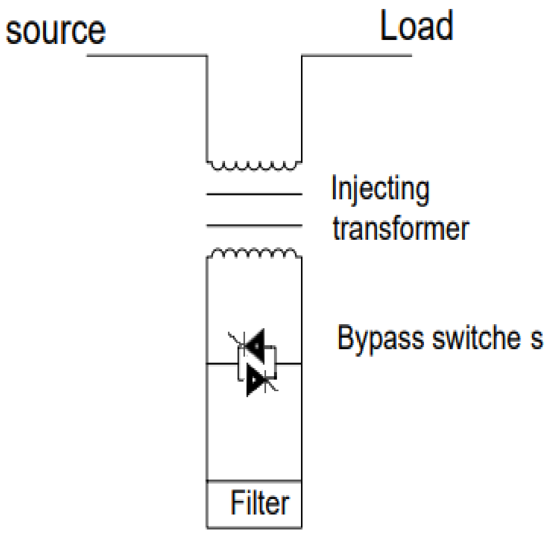

Figure (4) Control scheme for Distributed Dynamic Voltage Restorer (DDVR)

5-3. The state of the injection($V_{DDVR} > 0$):

In the event of injection, the required voltage is injected when a disturbance occurred and thus the DDVR is working.

6. Control of Distributed Dynamic Voltage Restorer (DDVR):

This study proposes employing the Synchronous Reference Frame (SRF) theory to generate reference voltages (Katole et al.,2017,216); (Ray et al.,2017,2). Through the single-phase approach, three phase-shifted sinusoidal waveforms are generated, each offset by 120 degrees, as expressed in Equations down. The primary voltage angle (θ) is obtained in the (d-q) coordinates through a Phase-Locked Loop (PLL) mechanism (Sathish Kumar et al.,2020,4208).

$$V_A = \sin(\omega t + \theta)$$
$$V_B = \sin(\omega t + \theta - 2\pi/3)$$
$$V_C = \sin(\omega t + \theta + 2\pi/3)$$

Transformation from abc to d-q coordinates is performed using the Park transformation, based on the relationships (2), as depicted in Figure (4). The conversion from abc to d-q coordinates is achieved through the inverse Park transformation.

$$\begin{bmatrix} u_d \\ u_q \\ u_0 \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \cos(\theta) & \cos(\theta - \frac{2\pi}{3}) & \cos(\theta + \frac{2\pi}{3}) \\ -\sin(\theta) & -\sin(\theta - \frac{2\pi}{3}) & -\sin(\theta + \frac{2\pi}{3}) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \begin{bmatrix} u_a \\ u_b \\ u_c \end{bmatrix} \quad (3).$$

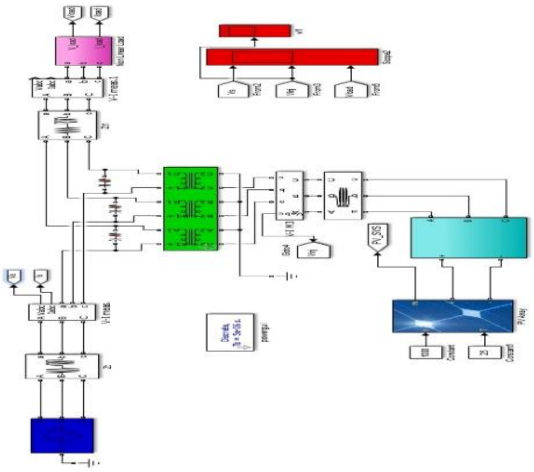

Figure (5) Transformation from abc coordinates to d-q coordinates

relying on the relations (3).

$$\begin{bmatrix} u_a \\ u_b \\ u_c \end{bmatrix} = \begin{bmatrix} \cos(\theta) & -\sin(\theta) & 1 \\ \cos(\theta - \frac{2\pi}{3}) & -\sin(\theta - \frac{2\pi}{3}) & 1 \\ \cos(\theta + \frac{2\pi}{3}) & -\sin(\theta + \frac{2\pi}{3}) & 1 \end{bmatrix} \begin{bmatrix} u_d \\ u_q \\ u_0 \end{bmatrix} \quad (4)$$

The control pulses are generated by PWM, which features a frequency of a fixed separation and connection, but its dynamic characteristics are not good compared to the non-liner control techniques (Jena et al.,2010,28); (Mishra et al.,2013,343). or no-liner methods such as the fixed delay package, which is one of the best non-written techniques, and it is characterized by the speed of response and ease of implementation and provides good dynamic features compared to linear methods.

In order to obtain the control pulses where the comparison of the ΔV-error signal, which represents the difference between the size and the reference voltage on the one hand and the voltage attached by the V_{inj} candidate on the other hand (Ezoji et al.,2009,157).

7. Modeling the System with Distributed Dynamic Voltage Restorer and Distributed Generation:

The model included Distributed Dynamic Voltage Regulator uses MATLAB/ SIMULINK.

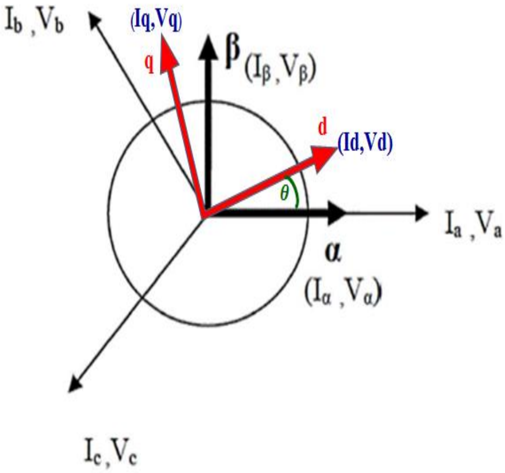

Figure 6 System model with Distributed Dynamic Voltage Restorer (DDVR) model and Distributed Generation (DG

In this research, the work of the proposed system was simulated in a capacity system that contains parameters shown in the table(1).

Table(1) System Element Parameters Used

Network Voltage	380 Volts
Frequency	50 Hz
Phase Voltage Peak Value	311 Volts
PV-System Voltage	899 Volts
Transformer Turns Ratio	1:1
Load Impedance	R = 12 Ω L = 35 mH
Line Impedance	R = 0.01 Ω L = 1 mH

Distributed generation was connected to the electrical distribution network at 380V level, which is a matrix of photovoltaic cells that have the specifications shown in the figure (7).

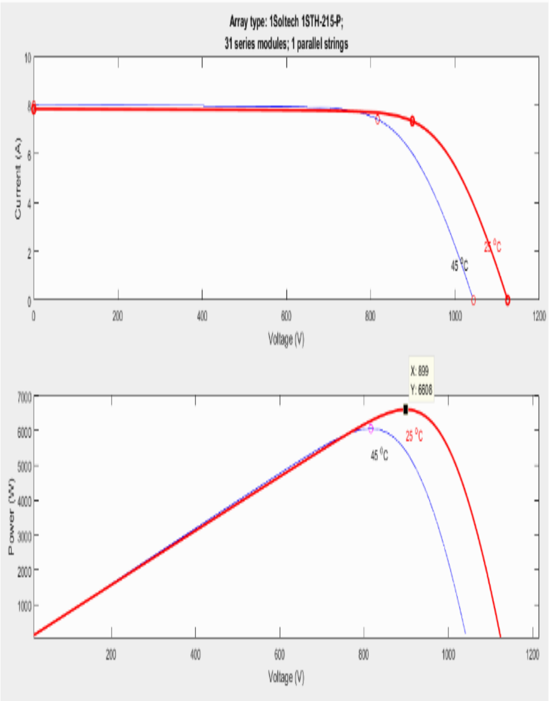

Figure (7) Parameters of the Photovoltaic Panel Matrix (Power-Voltage-Current) at Temperature 25°C

As for the specifications of the photovoltaic panels used, they are shown in the table (2).

Table (2) Specifications of Used Photovoltaic Panels

Model	1Soltech 1STH-215-P
Maximum Power	213.15 W
Open Circuit Voltage (Voc)	36.3 V
Voltage at Maximum Power point (Vmp)	29 V
Current at Maximum Power point (Imp)	7.35 A
Short-circuit Current (Isc)	7.84 A

8-Results and Discussion:

Multiple disturbance scenarios (symmetric and asymmetric) were modeled and simulated, including voltage sag, voltage swell, and voltage interruption, using MATLAB/Simulink/SimPowerSystems tools. Network voltage curves voltage, compensated voltage, and load voltage were plotted using MATLAB.

8-1. Symmetric Disturbance Case:

Subsection A: Voltage Sag Case:

The disturbance was simulated when three-phase fault occurred near the generator, as shown in Figures (8,9,10). The voltage sag case was processed from time (s) 0.08 to (s) 0.16. The curves illustrate network voltage, In this case, the DDVR begins to inject the voltage in the system, the injection voltage will maintain the stability of the system, and prevent load disconnection.

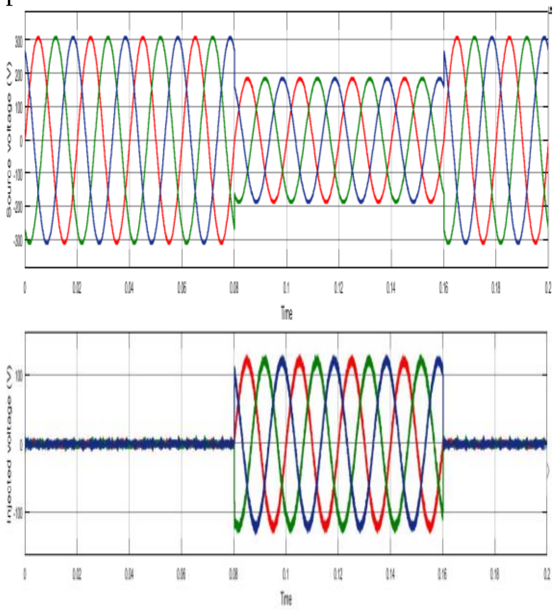

Figure (8) Network voltage

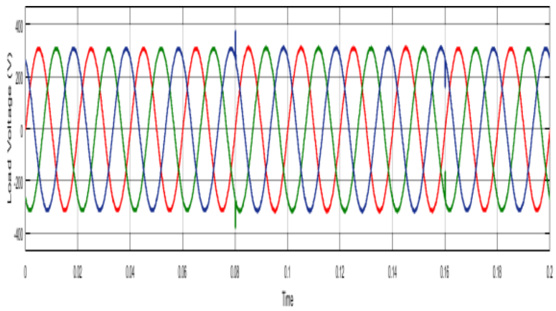

Figure (9) compensated voltage from DDVR

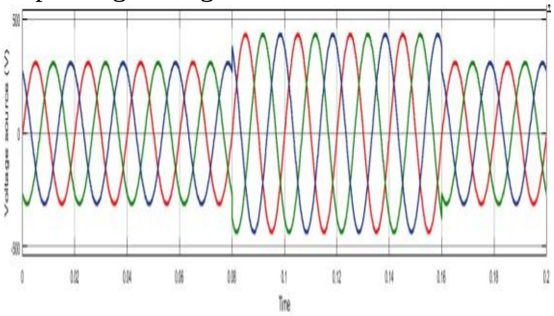

Figure (10) Load voltage

Secondly: Subsection B: Voltage Swell Case: The disturbance was simulated by generating the fault using a three-phase fault generator, as shown in Figure (9). The voltage swell case was processed from time (s) 0.08 to (s) 0.16. The curves illustrate network voltage, compensated voltage from the DDVR, and load voltage during this fault.

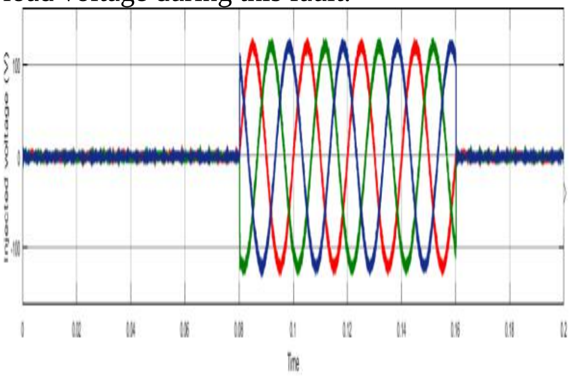

Figure (11) Network voltage

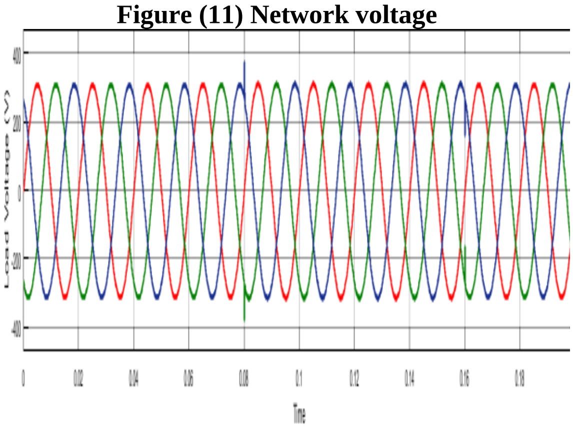

Figure (12) compensated voltage from DDVR

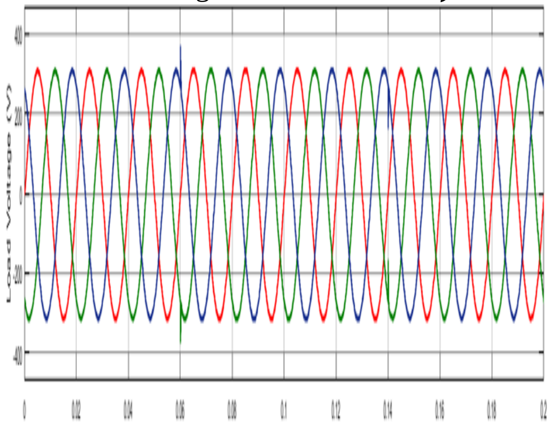

Figure (13) Load voltage

8-2. Asymmetric Disturbance Case:

The disturbance was simulated by generating the fault using a three-phase fault generator, as shown in Figure (10). The asymmetric disturbance case of a single-phase interruption was processed from time (s) 0.06 to (s) 0.12. The curves illustrate network voltage, In the case of a malfunction in the power system, the DDVR begins to inject the voltage in the system, the value of the right voltage will maintain the stability of the system to maintain the load voltage from the disturbances, compensated voltage from the DDVR, and load voltage during this case.

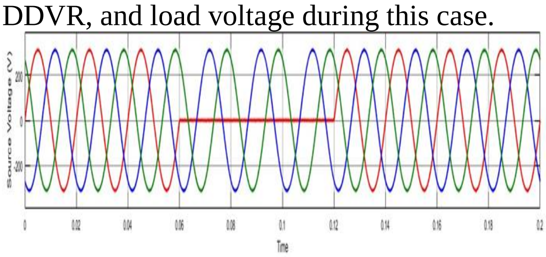

Figure (14) Network voltage

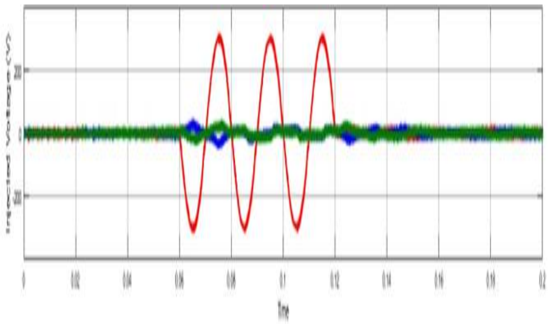

Figure (15) compensated voltage from DDVR

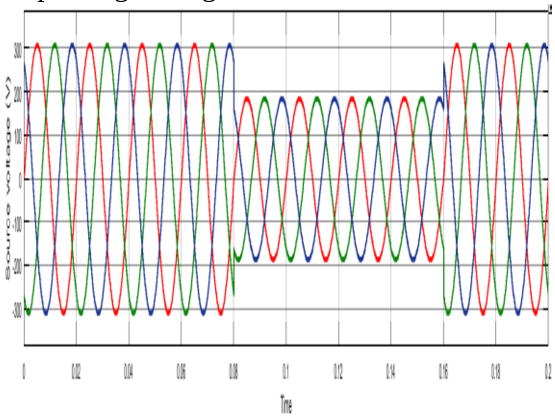

Figure (16) load voltage (single-phase interruption case)

9. Conclusions:

1- The dynamic voltage compensator (DDVR) played its role in compensating the load voltage instantaneously in the presence of distributed generation (DG).

2- The use of DDVR has greatly improved the load voltage waveform in various disturbance cases (symmetrical three-phase faults) or asymmetrical faults, and this reflects positively on loads, which are sensitive to voltage disturbances.

3- Distributed generation helps improve voltage in electrical distribution networks, and DDVR regulates voltage in normal working conditions and when there are voltage disturbances.

4-This study provides useful knowledge for researchers to develop the design of the DDVR and its control system to reduce voltage disturbances in electrical distribution networks.

5- When a photovoltaic station with a capacity of 6608 watts is connected to the network, this will provide a capacity provided by traditional thermal generation of approximately 11,233.6 kWh annually. This saves an amount of fuel equal to 2.6 tons equivalent annually, and this means reducing CO_2 emissions by more than 7.8 tons during the year.

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