Journal of Advanced Engineering Trends
ISSN : 2682 - 2091

Vol.42, No.1. January2023

http://jaet.journals.ekb.eg

Power Quality Improvement in Smart Distribution Grid Using Low-Cost Two-level Inverter DVR

Yahia M. Esmail [1], Gamal M. Dousoky [2]

[1,2] Electrical Engineering Department, Faculty of Engineering, Minia University, Minia, Egypt.

** Corresponding author E-mail: YahiaMEsmail@gmail.com*

ABSTRACT

The smart grid (SG) is a new scientific progress concept. Residential and commercial colonies and smart homes have many sensitive electrical devices and renewable energy systems (solar and wind). SG is greatly affected by Power Quality (PQ) disturbances. PQ has significant impacts on the low voltage smart grid, such as flicker, voltage sag/swell, and harmonics, causing substantial losses and disrupting the SG system. The smart home resident needs a clean and reliable electric power energy source without any PQ troubles. Dynamic Voltage Restorer (DVR) is a cost-efficient and promising static var device installed in series with transmission and distribution lines to protect PQ disturbances in electrical power systems. This research introduces an idea to improve PQ disturbances in the smart distribution grid (smart home) at the low voltage side using a Low-Cost Two-level inverter DVR. This study will use a two-level inverter topology to integrate with the DVR System to obtain a simple and straightforward Low-Cost Two-level Inverter DVR approach that is easy to use, flexible, and practical. In this research, the proposed DVR was designed and simulated in MATLAB/Simulink, where it shows excellent performance to overcome PQ-related disturbances such as voltage sag/swell, flicker, and harmonics with percentages close to 99%.

Keywords: *Power Quality, Two-level inverter DVR, Smart Grid, Smart Home.*

1. INTRODUCTION

The Flexible AC transmission system (FACTS) was in the 1980s[1]. For years, interest in FACT systems has increased significantly, as it maintains the electrical network's PQ and stability. FACTS are counted among the best solutions for improving a smart grid's power quality, reliability, and efficiency.

The beginning of the Dynamic Voltage Restorer (DVR) system was in August 1996 in North America. DVR is considered the best FACTs in protecting the electrical power systems from PQ disturbances despite its high cost that limited its use, especially in electrical distribution systems. DVR is also called Static Series Compensator (SSC) and Series Voltage Booster (SVB). The main features of the DVR are protecting sensitive loads, affordable price, small size, and simplicity of composition[2].

Revised:13 March, 2021, Accepted:14June , 2021

The utmost importance for consumers in the SG is electricity cost (Tariff), efficiency, and higher power quality. Utilities with smart power grids expend a lot to satisfy customers and give pure trouble-free electricity without any PQ troubles. The smart home is one of the essential components of the smart grid. It is composed of apartments and villas that use the latest technology. Such homes have an integrated information network that alerts the inhabitant of almost everything around him and controls it. A green smart home power system can recognize which devices are the worst power consumers when not used and disconnect them. If the family is away, SH can disconnect all standby customer devices[3]. In 1991 the first smart home was in Germany, and by the end of 1995, 5% of German households applied smart home specifications and reduced energy consumption. Now smart homes are widely spread all over the world. The number of smart homes in Europe has reached 30 million, reaching 38 million in North America [4].

Power quality (PQ) will play an essential role in power systems, especially in the smart grid. PQ is defined as any deviations in frequency, current, or voltage that result in customer equipment failure. Most inferior PQ sources are concentrated in wind turbine generation, Photovoltaic (PV) systems, inverters and rectifiers, battery chargers, power electronics, Uninterruptible Power Supply (UPS), and drivers.

PQ has significant impacts on the smart grid, such as flicker affects the human brain reacts and corrupts vision, increasing losses, reducing production, reducing the performance of computers and sensitive devices, security system failure, and unwanted triggering UPS relays, significantly impacts on the transfer of data via smart meters, and induction motor breakdown. [5]. Given the above challenges, SG operators are still mandated to enforce PQ standardized levels to reduce energy waste, minimize the generation cost, avoid penalties, increase power system reliability, increase the equipment lifetime, and reduce the equipment outage times.

PQ issues classification is presented in a simple chart, shown in Fig.1. One smart grid/home aims to improve the power system quality by saving energy and cost, penalty savings, increased reliability, increased life of the equipment, reduced temperature rise of the equipment, and reduced equipment failure. Table 1 displays power quality standards, according to IEC and IEEE standards.

Table 1
Power quality standards[6].

Category	Typical Duration	Typical Amplitude
Harmonics	Steady-state	0 – 20%
Voltage sag	0.5 to 30 cycles	0.1 – 0.9
Voltage swell	0.5 to 30 cycles	1.1 – 1.9
flicker	Intermittent	0.1 – 9%
Interruption	0.5 cycles to 30 s	> 0.1 pu
Undervoltage	> 1 min.	0.8 – 0.9
Overvoltage	> 1 min.	1.1 – 1.2
DC Offset	Steady-state	0 – 0.1%
Noise	Steady-state	0 – 1%

Fig. 1. PQ issues classification.

Maintaining and improving PQ levels in SGs remains a critical task. Enormous potentials for achieving higher PQ levels comes from smart grid/home technologies and related operational concepts and principles. Higher PQ levels will increase observability and data exchange, improved network flexibility, and saving energy by up to 40% of regular consumption. Smart grid/homes should also provide functionalities and services for maintaining high sustainability, security, and affordability of electricity supply.

Voltage source inverters are classified based on the no. of levels in output voltage as a two-level inverter and multilevel inverters (diode clamped, flying capacitor, and cascaded H-bridge). Inverters with three or more levels are called multilevel converters. The two-level inverter comprises six groups of active switches; each switch is an Insulated-gate bipolar transistor (IGBT) switching device. The switches must have bidirectional current carrying capability and unidirectional voltage blocking ability; thus, an IGBT fulfills this requirement. Two-level topology uses two transistors per phase in a series connection. The only advantage of multilevel topology over two levels is that the switching losses are minor during very high frequency (16-32 kHz).

Authors in [7],[8],[9] did not give a good design for the DVR system and did not solve most of the PQ disruptions combined. They did not address smart distribution networks and their connection to renewable energy systems, and they also did not manage a low voltage, low-cost two-level inverter DVR system.

In[10],[11],[12] Several drawbacks limit multi-level inverter use in several applications: the number of devices increases significantly as the number of diodes increases with each level, making the circuit complicated and more expensive. In some cases, it reduces reliability as well. Thus, a multi-level transformer requires multiple DC sources, which is a big problem by splitting a single DC source into various sources using series-connected capacitors. And therefore, makes the system more expensive. Since multi-level switches have many switches, it is necessary to generate multiple-gate pulses, requiring sophisticated digital signal processors that support Pulse-width modulation (PWM).

In [13], the authors show the effectiveness of a Genetic Algorithm GA-based Thyristor Controlled Series Compensation (TCSC) damping controller to damp the oscillation system, thus improving the network stability. As for our research, the matter is entirely different as we are developing an affordable DVR system to be economical and more effective in improving the power quality in a low voltage smart distribution grid.

This research presents an affordable Low-Cost Two-level inverter DVR device in the smart distribution grid at the low voltage side. In our study, we will integrate a two-level inverter topology with the DVR system because of the simplicity of the switching method (PWM) and ease to control, and its cost is also lower than other DVR topologies such as multilevel inverters with a ratio greater than 46%, as will be illustrated and detailed in the next section. A resident can install it in his smart home or any other residential or commercial colonies to protect all PQ distortions. This study uses MATLAB/Simulink to simulate a Low-Cost Two-level DVR in SH at the low voltage side to show high-performance protection against all PQ disruptions such as voltage sag, swell, and flicker, and harmonics. This paper will connect the smart home to the PV system, see its impacts, how this DVR overcame these problems, and evaluate the smart grid and PV system's reliability with the proposed DVR during various faults. Here the problem values that appear will be compared to standard values. The results obtained from this study are very motivating and can be used in many residential and commercial colonies and smart homes.

This manuscript will illustrate in section 2 how the DVR works. Section 3 explains the small-scale DVR design for improving the power quality of SHs. Furthermore, the results and discussion are addressed in Section 4. Finally, Section 5,6 addresses the main conclusions and future work.

2. DYNAMIC VOLTAGE RESTORER (DVR)

The DVR is one of the most efficient custom power electronic FACT devices. The DVR (Dynamic Voltage Restorer) is a series-connected FACT device that injects additional voltage into the grid to mitigate PQ nuisances such as voltage sag, swell, fluctuation, and harmonics. DVR is the best cost-effective solution to alleviate voltage quality, especially in sensitive loads. DVR offers an injection of the series voltage into the system to mitigate PQ disturbances, while STATCOM provides an injection of shunt current into the system. The DVR is less in size and cost compared to STATCOM and other FACT devices [14].

The DVR power circuit consists of a coupling booster transformer, a harmonic filter, a voltage source inverter, an energy storage device, a bypass switch, and a control system, as shown in Figure 2. The booster transformer's utility is the isolation of the DVR circuit from the distribution network and the increased voltage derived from the VSI system. The DVR used in this paper employs three single-phase transformers. The harmonic filter's primary function is to reduce harmonics from the DVR system or electrical distribution network. Bypass Switch protects DVR from overloading and faults, connected in series with the electrical grid[15]. In our scientific research, we will use a low voltage small-scale of all these DVR components. The energy storage (ES) device and a DC - link provide DVR's real power required during injection mode.

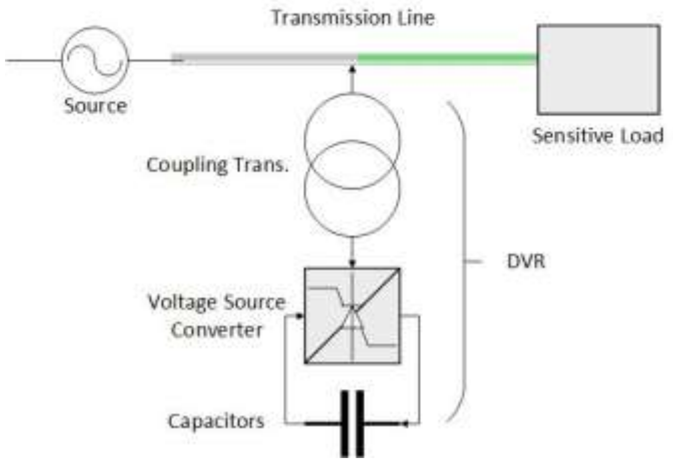

Fig. 2. DVR structure.

The DVR principle injects a required voltage to restore the desired voltage and absorb or generate controllable reactive and real power at the load side to improve PQ. It is used for the gate turn-off thyristor (GTO) switch in the running pulse width modulated (PWM) inverter [16].

DVR control of compensating device performs these three steps, detection of voltage swell/sag in the system, comparison with programable value, and generation of GTO switch pulses to the VSI inverter to generate the DVR required output voltages, which will compensate the voltage swell/sag and other voltage quality distortions, which is called injection mode. DVR works in standby mode in the normal case unless abnormal cases occur in the network. The bypass switch in standby mode is turned on, and all the inverter switches are turned off. If the fault current reduces, then the DVR operation mode turns to the protection mode that DVR is protected from the overload and faults on the load-side, as shown in Fig. 3 and Fig. 4. PI controller of DVR is shown in Fig 4. PI controller is the most common in DVR systems, and one of its main advantages is efficiency and ease to use. Kp is the proportional gain, and Ki is the integral gain.

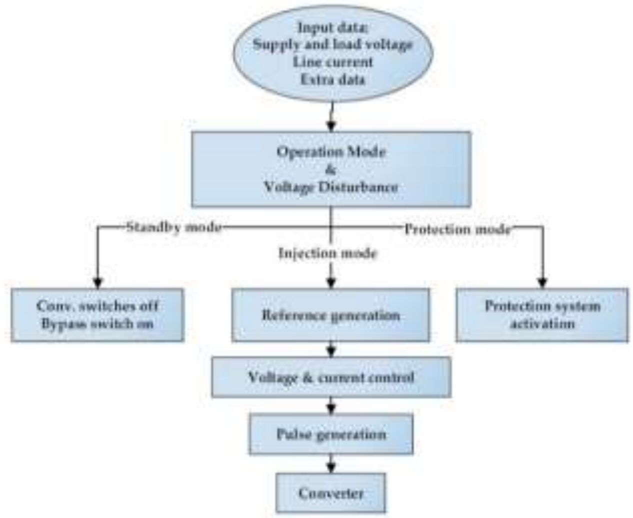

Fig. 3. DVR control strategies.

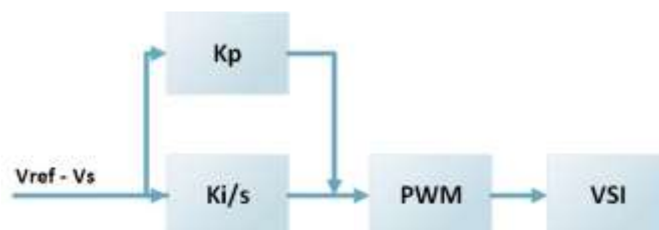

Fig. 4. PI controller of DVR.

Fig. 5 illustrates the equivalent circuit diagram of DVR. The system impedance (Z_{TH}) depends on the load bus fault[17]. When the system voltage (V_{TH}) is reduced, the DVR injects a series voltage (V_{DVR}) through the booster transformer to preserve the V_L value. The interpretation of the series injected voltage of the DVR equation is stated as follows:

$$V_{DVR} = V_L + Z_{TH} I_L - V_{TH} \qquad (1)$$

Where,

$V_{(L)}$ is the desirable load voltage.

$Z_{(TH)}$ is a load impedance.

$I_{(L)}$ load current

$V_{(TH)}$ is a system voltage during a fault condition.

The load current I_L is given by:

$$I_L = \frac{P_L + jQ_L}{V} \qquad (2)$$

Taking V_L as a reference then equation (1) can be written in the following form:

$$V^*_{DVR} = V_L^{\angle 0} + Z_{TH}^{L(\beta-\theta)} - V_{TH}^{L\delta}$$
$$\theta = \tan^{-1}\left(\frac{\theta_L}{P_L}\right) \qquad (3)$$

That θ is the load Power factor and α, β and δ are the phase-angles of the V_{DVR}, Z_{TH}, and V_{TH}

The complex power output of the DVR as:

$$S_{DVR} = V_{DVR} I_{DVR}^{*} \quad (4)$$

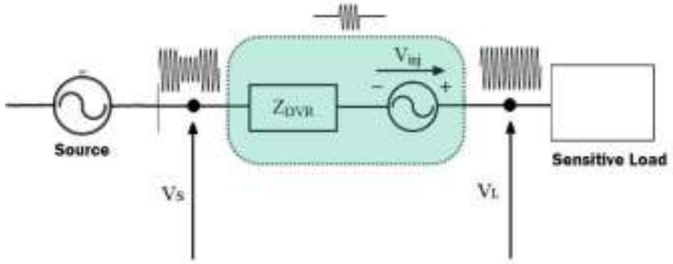

Fig. 5. DVR equivalent circuit diagram.

In our study, the best choice is the two-level converters topology because of the simplicity of the switching method (PWM), and its cost is also lower than other inverter topologies such as multilevel inverters, as shown in Fig. 6. Two-level inverters DVR systems cannot be used in medium voltage networks as the switches cannot withstand medium voltage. In this topology, the practical results show excellent performance with fast speed calculation time approx. 1.66 faster than others and program execution easily[18].

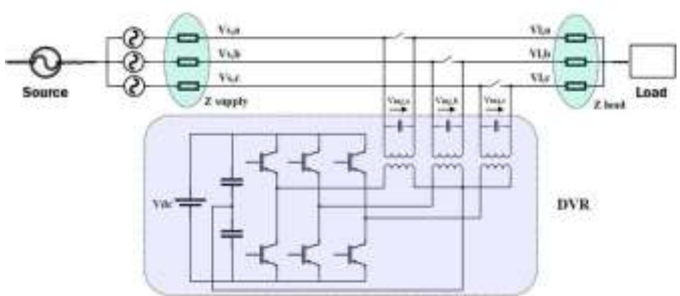

Fig. 6. Two-level converters DVR topology.

3. Low-Cost Two-Level Inverter DVR Design

The study here will be on one of the smart homes, an essential component of the smart distribution grid. Smart homes have many sensitive electrical/electronic components such as non-linear loads and a PV solar system that may represent a source of PQ disturbances. In this section, the Low-Cost Two-level inverter DVR performance is illustrated to overcome PQ disturbances in the smart home. Five cases are selected to examine the performance of the DVR, which is often abundant in the smart grid-smart home, and they are as follows voltage sag, voltage swell, voltage flicker, harmonics, and DVR ability to overcome power instability (faults). The smart home used in this research is a 380 V three-phase low voltage system with a DVR 10 KVAR at a 45 KW load. Furthermore, the actual cost of making this system is 70 $/ KVAR, which is، on average, 700 Dollars per smart home. Thus, this cost is acceptable for maintaining the electric power quality and stability with high efficiency in a smart home and avoiding any losses.

The three-phase 11kV, 50 Hz power system is connected to the smart home-smart grid via a step-down transformer (11kV/380V). The design of Low-Cost Two-level inverter DVR in Fig. 7. The base voltage at DVR and feeder (source) bus and load bud: 380V. The designed proposed DVR MATLAB/Simulink model is shown in Figure 7. The DVR system is connected in series to the electrical network immediately after the source bus and directly before the smart home, as shown in Fig. 8. The electrical loads for the smart home here are 45 KW, while the rating of the DVR is 10 KVAR. The operation time of this MATLAB/Simulink model is 0.1 seconds. Table 2 addresses the Low-Cost Two-level inverter DVR system MATLAB/Simulink parameters.

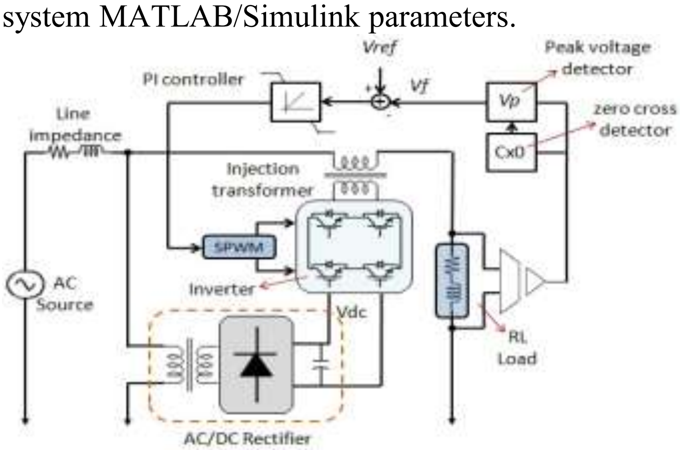

Fig. 7. Design of Two-level inverter DVR.

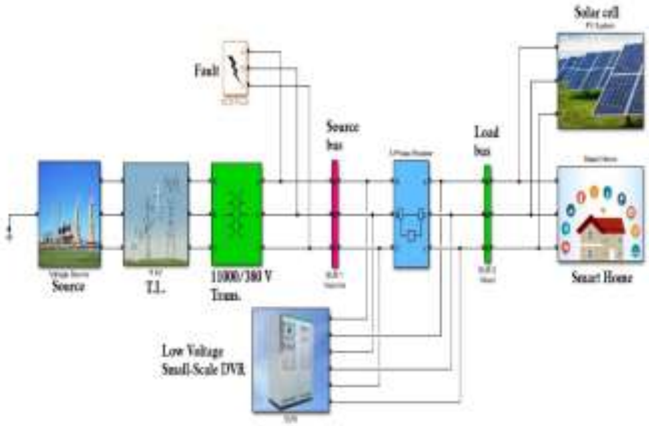

Fig. 8. Low-Cost Two-level inverter DVR with a smart home-smart grid model.

Table 2
Two-level inverter DVR System Parameters.

System Parameter	Value
Supply feeder voltage	11 kV
Distribution Trans.	11000/380 V
DVR and Load voltage	380 V
Frequency	50 Hz
SH Load value	45 KW
DVR rating	10 KVAR
DC capacitor	200 µF
Booster Tr. TR	1:10
DC battery	500 V
Filter Inductance	10 mH
Filter Capacitance	0.1 µF
Controller type	PI Controller
Power factor	0.97 (lagging)
Simulation time	0.1 Second

The essential component of the DVR system, especially in terms of price, is the inverter. The inverter cost is affected mainly by the DC-link capacitor, IGBT, and the filtering components, while the rest electronics have relatively insignificant effects. Also, the cost of a three-level inverter includes the clamped diode, which is not needed in a two-level configuration. We will analyze the prices and compare the two and three-level inverter systems according to the average global market prices for 2021, as shown in tables 3,4.

Table 3
Cost analysis of 2-level inverter

Part	**Unit price $**	**No. of units**	**Total unit prices $**
IGBT	20	3	60
Capacitor	60	6	360
Total cost $			420

Table 4
Cost analysis of three-level inverter

Part	**Unit price $**	**No. of units**	**Total unit prices $**
IGBT	20	3	60
Capacitor	60	8	480
Diode	30	6	180
Total cost $			720

It is evident from the previous comparison that the 2-level inverter DVR is 46% cheaper than the three-level inverter DVR system.

4. RESULTS AND DISCUSSION

A. Performance of the Proposed DVR with Voltage Sag in Smart Home

In this section, the DVR performance is investigated to overcome voltage sag. Voltage sag/dip is the most common type of PQ disruption in any electrical network. In this case, the voltage sag reaches 0.54 pu in the period between [0.04 - 0.06] seconds, as shown in Fig. 9. DVR can restore the voltage of approximately one pu in 0.5 milliseconds, as shown in Fig. 10.

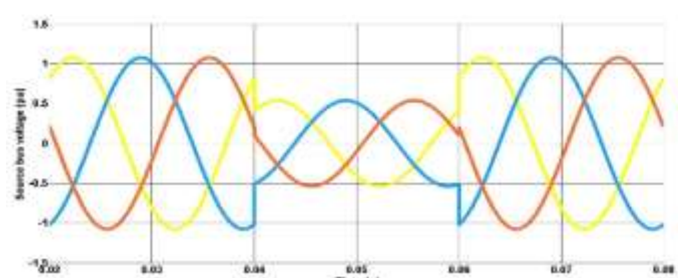

Fig. 9. Source bus voltage sag before DVR.

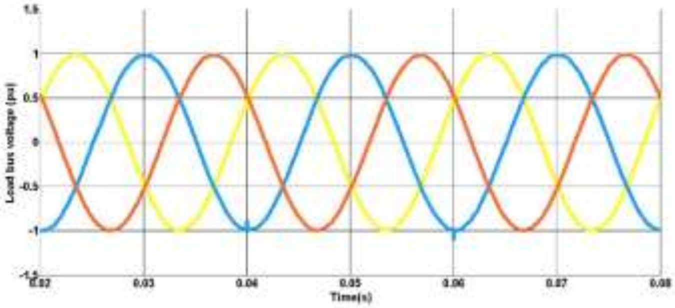

Fig. 10. Load bus voltage after DVR.

B. Performance of the Proposed DVR with Voltage Swell in Smart Home

In this section, the ability of the DVR is investigated to overcome voltage swell. In this case, the voltage swell reaches 1.6 pu in the period between [0.04 - 0.06] seconds, as shown in Fig. 11. DVR can restore the voltage of approximately one pu in 0.5 milliseconds, as shown in Fig. 12.

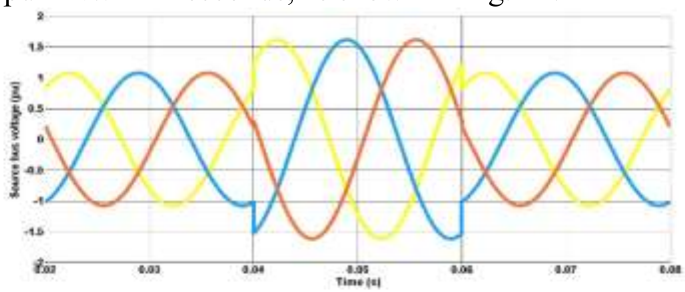

Fig. 11. Source bus voltage swell before DVR.

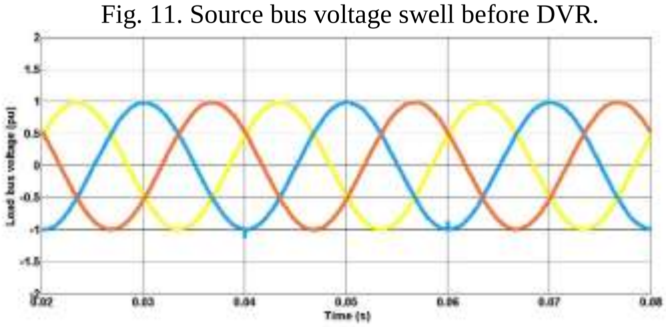

Fig. 12. Load bus voltage after DVR.

C. Performance of the Proposed DVR with Voltage Fluctuations in Smart Home

In this section, the DVR performance to overcome voltage fluctuation is investigated. In this case, the voltage fluctuation reaches 1.5 pu in the period between [0.04 - 0.06] seconds and 0.65 pu in the period between [0.06 - 0.08] seconds, as shown in Fig. 13. DVR can restore the voltage of approximately one pu in 0.5 milliseconds, as shown in Fig. 14.

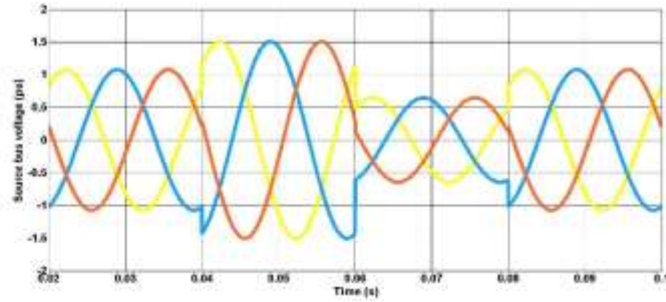

Fig. 13. Source bus voltage fluctuation before DVR.

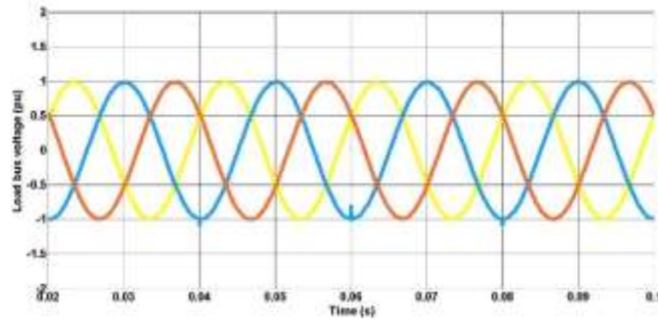

Fig. 14. Load bus voltage after DVR.

D. Performance of the Proposed DVR with Voltage Solar cell Harmonics in Smart Home

In this section, the smart home is connected to a solar cell (10 KW). This condition has resulted in voltage harmonics at the source bus by 13.42%, as shown in Fig. 15. Figure 16 indicates that the STATCOM reduces the load bus voltage harmonic (THD) to 0.04%.

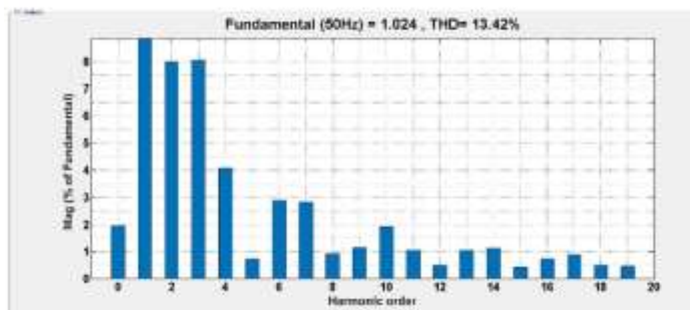

Fig. 15. THD of source bus voltage before DVR

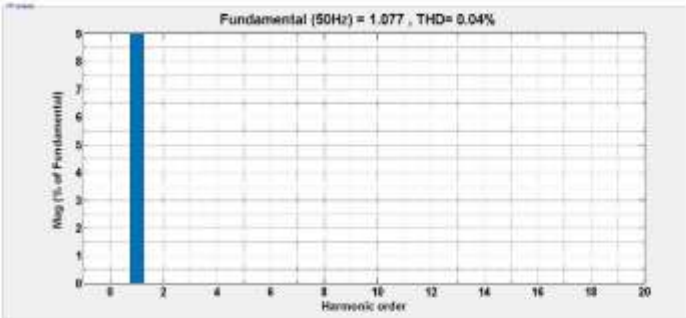

Fig. 16. THD of load bus voltage after DVR.

E. Performance of the Proposed DVR with Transient Fault in Smart Home

A double line to ground transient fault is applied during the time of 0.03s - 0.08s, which causes system instability and is considered one of the most dangerous fault types. This fault results in the voltage drop (0.4 pu) and network instability shown in Fig. 17. Fig. 18 indicates that the DVR overcomes this fault, limits voltage to nearly one pu (pure sinusoidal wave), and maintains network stability within 0.5 milliseconds. Thus, it can overcome the applied fault efficiently.

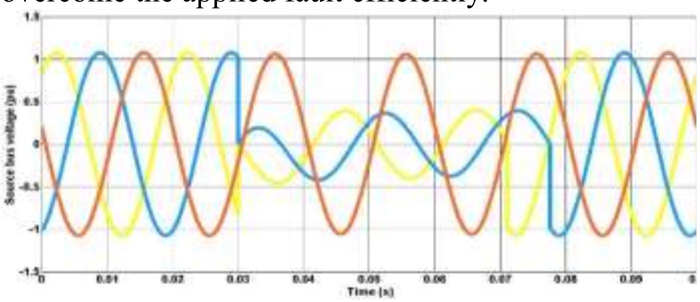

Fig. 17. Source bus DL-G transient fault before DVR.

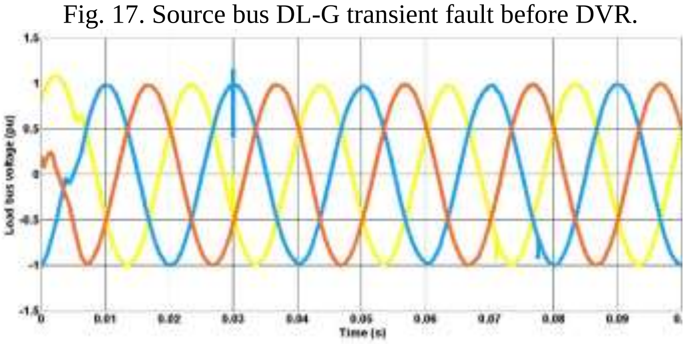

Fig. 18. Load bus voltage after DVR.

In [19], the authors only describe mathematical analysis for a three-phase, two-level inverter design. In [20], STATCOM using a two-level inverter is presented in this paper in a medium voltage network (11 kV). Paper [7] only shows DVR performance in mitigating voltage sags/swells.

Our paper gives a complete and detailed analysis study to solve the expected PQ problems in smart distribution grids at the low voltage side. In this study, the two-level inverter topology was integrated with the DVR system to obtain an affordable DVR. The previous results demonstrate the ability of the proposed DVR system to overcome PQ-related disturbances such as voltage sag/swell, flicker, and harmonics with remarkable efficiency and speed and obtain a pure sin wave in a low voltage grid. This study showed the importance of the proposed DVR system with the installation of renewable energy (solar), as it showed an ideal performance in overcoming the harmonic problems resulting from it. This study has also shown great effectiveness in overcoming the instability of a low voltage grid caused by different types of faults. Accordingly, anyone can install this inexpensive system in his home, shop, or anywhere on a low voltage grid to enjoy clean electrical power without any problems or losses, or penalties.

5. CONCLUSION

The purpose of this research is to obtain clean energy without any PQ problems through a simple, easy, and low-cost system that can be installed anywhere on low voltage networks in the smart grid. In this paper, the Low-Cost Two-level inverter DVR is designed and simulated to mitigate power quality disturbances in the smart grid-smart home using MATLAB/Simulink. The proposed DVR is considered cost-efficient and the best static var devices installed in series with smart homes or residential and commercial colonies to protect PQ disturbances. This research demonstrated improved PQ disturbances such as voltage sag, swell, flicker, harmonics, and maintaining the smart home's stability in the smart home using the proposed DVR. The proposed DVR cost does not exceed 700 $ for one SH with electrical loads of 45 kilowatts; hence it is a very economical solution. The proposed DVR design's main benefits are its quick response to restore voltage by percentage close to 99% within high response 0.5 ms, simple control, and low cost. It is evident from this study that the 2-level inverter DVR is 46% cheaper than the three-level inverter DVR system. Thus, the smart home resident will get a clean and reliable electric power energy source without any PQ troubles. The results obtained from this study are very motivating and can be used in many smart homes. Finally, a Two-level inverter DVR is the perfect choice for a modern smart home or residential and commercial colonies which contributes significantly to improving the quality of the entire network.

6. FUTURE WORK

A future application of this research is the development and use of FACT systems in both the AC-DC hybrid smart grid, optimal use of vehicles to home (V2H), and vehicles to grid (V2G), fuel cell (FC), and super-capacitor systems. Consequently, developing the latest approaches and perspectives to protect smart grids from the danger of bad PQ and instability is necessary. The Low-Cost Two-level inverter DVR system can design and apply in the laboratory.

REFERENCES

[1] Y. M. Esmail, S. K. Elsayed, and M. A. Mehanna, "Mitigation of Voltage Fluctuation in Power Distribution System Using D-STATCOM," *Indones. J. Electr. Eng. Comput. Sci.*, vol. 2, no. 3, p. 530, 2016, doi: 10.11591/ijeecs.v2.i3.pp530-536.

[2] N. J. Woodley, L. Morgan, and A. Sundaram, "Experience with an inverter-based dynamic voltage restorer," *IEEE Power Eng. Rev.*, vol. 17, no. 9, p. 43, 1997.

[3] E. Ancillotti, R. Bruno, and M. Conti, "The role of communication systems in smart grids: Architectures, technical solutions and research challenges," *Comput. Commun.*, vol. 36, no. 17–18, pp. 1665–1697, 2013, doi: 10.1016/j.comcom.2013.09.004.

[4] D. Sarala, "Smart Homes and Home Automation," *Int. J. Innov. Res. Dev.*, vol. 5, no. 2, pp. 332–338, 2016.

[5] F. C. Argatu, V. Brezoianu, V. V. Argatu, B. A. Enache, F. C. Adochiei, and T. Icleanu, "Power Quality Analyzer for Smart Grid-Smart Home Applications," *2019 54th Int. Univ. Power Eng. Conf. UPEC 2019 - Proc.*, no. Section 2, pp. 1–4, 2019, doi: 10.1109/UPEC.2019.8893501.

[6] M. A. S. Masoum and E. F. Fuchs, "Introduction to Power Quality," *Power Qual. Power Syst. Electr. Mach.*, pp. 1–104, 2015, doi: 10.1016/b978-0-12-800782-2.00001-4.

[7] sanjay H. Chaudhary and gaurav Gangil, "Analysis, Modeling and Simulation of Dynamic Voltage Restorer (DVR)for Compensation of Voltage for sag-swell Disturbances," *IOSR J. Electr. Electron. Eng.*, vol. 9, no. 3, pp. 36–41, 2014, doi: 10.9790/1676-09313641.

[8] A. V. Ital and S. A. Borakhade, "Compensation of voltage sags and swells by using Dynamic Voltage Restorer (DVR)," *Int. Conf. Electr. Electron. Optim. Tech. ICEEOT 2016*, vol. 4, no. 2, pp. 1515–1519, 2016, doi: 10.1109/ICEEOT.2016.7754936.

[9] F. A. L. Jowder, "Design and analysis of dynamic voltage restorer for deep voltage sag and harmonic compensation," *IET Gener. Transm. Distrib.*, vol. 3, no. 6, pp. 547–560, 2009, doi: 10.1049/iet-gtd.2008.0531.

[10] A. Bughneda, M. Salem, A. Richelli, D. Ishak, and S. Alatai, "Review of multilevel inverters for PV energy system applications," *Energies*, vol. 14, no. 6, pp. 1–23, 2021, doi: 10.3390/en14061585.

[11] A. Hassan, X. Yang, W. Chen, and M. A. Houran, "A state of the art of the multilevel inverters with reduced count components," *Electron.*, vol. 9, no. 11, pp. 1–27, 2020, doi: 10.3390/electronics9111924.

[12] J. Buczek and V. Ivankevych, "Practical Utility PV Multilevel Inverter Solutions," pp. 1–9, 2021.

[13] M. S. Alam, M. Shafiullah, M. I. Hossain, and M. N. Hasan, "Enhancement of power system damping employing TCSC with genetic algorithm based controller design," *2nd Int. Conf. Electr. Eng. Inf. Commun. Technol. iCEEiCT 2015*, no. May, pp. 21–23, 2015, doi: 10.1109/ICEEICT.2015.7307353.

[14] R. Pal and S. Gupta, "State of the Art: Dynamic Voltage Restorer for Power Quality Improvement," *Electr. Comput. Eng. An Int. J.*, vol. 4, no. 2, pp. 79–98, 2015, doi: 10.14810/ecij.2015.4208.

[15] D. V. Tien, R. Gono, and Z. Leonowicz, "A multifunctional dynamic voltage restorer for power quality improvement," *Energies*, vol. 11, no. 6, pp. 1–17, 2018, doi: 10.3390/en11061351.

[16] A. Benali, M. Khiat, T. Allaoui, and M. Denaï, "Power Quality Improvement and Low Voltage Ride Through Capability in Hybrid Wind-PV Farms Grid-Connected Using Dynamic Voltage Restorer," *IEEE Access*, vol. 6, pp. 68634–68648, 2018, doi: 10.1109/ACCESS.2018.2878493.

[17] sanjay haribhai Chaudary and Mr. Gaurav gangil, "Mitigation of Voltage sag/swell using Dynamic Voltage Restorer (DVR)," *IOSR J. Electr. Electron. Eng.*, vol. 8, no. 4, pp. 21–38, 2013, doi: 10.15662/IJAREEIE.2015.0410036.

[18] R. Mali, N. Adam, A. Satpaise, and A. P. Vaidya, "Performance Comparison of Two Level Inverter with Classical Multilevel Inverter Topologies," *Proc. 2019 3rd IEEE Int. Conf. Electr. Comput. Commun. Technol. ICECCT 2019*, pp. 1–7, 2019, doi: 10.1109/ICECCT.2019.8869115.

[19] M. Ali, “Mathematical Driving Model of Three Phase, Two Level Inverter by (Method of Interconnected Subsystem),” *Iraqi J. Electr. Electron. Eng.*, vol. 13, no. 1, pp. 73–82, 2017, doi: 10.37917/ijeee.13.1.10.

[20] A. Bharadwaj, S. Maiti, N. Dhal, and S. Chakraborty, “Control of Two Level Converter based STATCOM with Battery and Ultracapacitor,” *2019 Natl. Power Electron. Conf. NPEC 2019*, 2019, doi: 10.1109/NPEC47332.2019.9034874.