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QUALITY CONTROL OF POWER SYSTEM USING DG_UPQC WITH AI BASED SWITCHING MODULATION TECHNIQUE

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Abstract-: Problems with power quality (PQ) are those which cause the voltage and/or current to deviate from the nominal sine wave. Voltage sags/swells and harmonic currents are typically the focus of P-Q issues. Recently, it has become more common to take Custom Power (CP) devices into usage for addressing these power quality issues. The Unified Power Quality Conditioner (UPQC), which simultaneously lowers load current and supply voltage concerns, is one of the CP devices. In this study, we suggest the UPQC in combination with a hybrid solar-wind energy resource to address power quality (PQ) issues in power systems. The UPQC proves effective in mitigating voltage sags/swells, harmonic currents, and enhancing power outcomes. Through simulations in MATLAB/SIMULINK, the proposed system achieves a 3.5% increase in active power, reduces reactive power to 52.85 V_{ar}, and enhances the power factor from 0.91 to 0.96. Additionally, it significantly reduces Total Harmonic Distortion (THD %) in both current as well as voltage waveforms, making UPQC a promising solution for enhancing power quality in hybrid energy systems.

Keywords: UPQC, Evolution Strategy (ES), Distributed generation (DG), Power Quality, Hybrid system.

1. Introduction

One of the primary factors behind modern infrastructure and developments is energy. Energy is becoming more and more important in every part of life, including the home, business, transportation, agriculture, health, education, and entertainment [1]. Global energy demand is increasing quickly as a consequence of factors like population growth, urbanization, and socioeconomic progress. Fossil fuels account for over 80% of the world's energy needs [2]. There are numerous difficulties with the situation where fossil fuels dominate energy. In comparison to rising energy demand, there is a diminishing demand for conventional fossil fuel reserves[3]. People frequently face issues due to fluctuating energy prices, particularly in developing nations. In addition, obtaining supplies from geopolitically unstable nations and regions carries dangers to energy security. Another major problem with the energy landscape is climate change, as burning fossil fuels has been determined to be the primary contributor to greenhouse gas emissions [4].

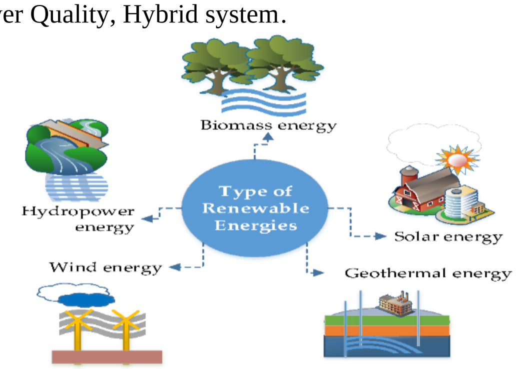

Figure 1: Types of Renewable Energies [5]

Renewable energy has a promising future, and nations have made smart investments in the generation of RE electricity. In addition, there are several opportunities in the transportation and heating and cooling industries. With over 29% of global energy consumption, the transportation sector is the second-largest energy terminal consumer worldwide. Additionally, despite the fact that heating and cooling require more energy than power generation and transportation, they still account for almost half of total terminal energy consumption [6].Decentralization in the power sector helps to promote the renewable energy sources development, which can mitigate the fossil fuels dependency. In recent years, photovoltaic (PV) as well as wind power have shown 4% and 7% global growth, respectively. In the last five years, PV and wind increased on average by 27% and 13%, respectively.

There are a number of contrasts between conventional generation and variable renewable energy (VRE). There are 6 fundamental characteristics of VRE generator output, including the primary resource's variable, small, and modular VRE generators, which differ from conventional generators, as well as the fact that the VRE is non-synchronous and unpredictable, even though there may be low initial costs [7].

2. Effect of Photovoltaic Systems (PVS) on The Power System Stability

The California Independent System Operator (CAISO) conducted a study on PVS voltage and reactive power responses for various connection types. The large percentage of PV linked to the sub-transmission network has been reported to render overvoltage issues unavoidable. It was also mentioned that Static Var Compensators (SVCs) led to increased transient overvoltages in a system with PV. The primary cause of this has been identified as the prolonged injection reactor power of SVCs into the system as a result of their slow operating speed after the fault was cleared. Voltage magnitudes appear to be the most impacted system parameters, adhering to the steady-state analysis carried out for PV penetration by [8]. In particular at penetration levels of 20% and above, overvoltages developed in the transmission line busbars. The voltage drops following a fault were found to be greater in a system with significant transient PV penetration.

The goal of this study is to design and simulate a system utilisingUPQC in MATLAB/SIMULINK, which is integrated with a hybrid solar-wind energy generation resource. The control system of the UPQC Shunt device will be modified using an evolutionary technique with slight architectural adjustments to evaluate the system's performance under different loading conditions. The primary focus is to analyze the power outcomes, enhance the active power, and achieve reactive power balancing by effectively employing the UPQC within the hybrid energy system. Through these efforts, the project aims to improve the overall power quality and efficiency of the system while ensuring stable and reliable operation.

3. Literature Review

According to **W.U. Tareen et al. [9]**, deep integration of renewable energy sources, such solar photovoltaic (PV) and wind turbine (WT) energy, relies primarily on the development of precise power quality techniques and affordable technology developments in global emissions. Innovative distributed generation systems use grid-connected inverters as essential parts. In order to convert power, the inverter connects systems for power distribution networks and renewable energy sources. Numerous current and voltage harmonics have an impact on the system performances in grid-connected systems. The operation of power networks and systems, as well as the increasing demand for nonlinear loads and renewable energy sources, are both impacted by highly unstable devices in a manner similar to this. Active power filters (APFs), static var generators, and passive filters (PFs) are effective APFs solutions. But PFs add to the cost, size, and weight of a high-power system. This study intends to investigate the most advanced APFs with the least number of power switches and with a special concentration on the size, weight, and cost reduction of grid-connected inverters. The use of reduced-switch-count APF inverter topologies like AC-AC, back-to-back, and common leg has been the subject of numerous research that have examined and assessed single-phase and three-phase systems. Recently, a lot of focus has been placed on wind energy conversion technologies, transformer-less inverters, multilayer as well as multifunctional PV inverters based on the APF, and cost-effective methods forthe reduction ofno. of components. The approaches used at this point to develop inverter-based components for renewable energy systems are presented, along with their drawbacks. This review could therefore be helpful to industrial researchers who are looking to enhance power quality in PV and WT energies as well as power distribution network systems.

Enhancing the power of grid-connected solar and wind energy systems (PV-WE) when coupled with energy storage systems (ESS) and electric vehicles (EVs) is the main objective of **K. Sarita et al.'s [10]** research. The only study publications that have been emphasized in the literature are those which concentrate on PV, PV-ESS, WE, and WE-ESS.In the currently available literature, techniques for power enhancement have been identified, consisting the Unified Power Flow Controller (UPFC), Static Var Compensator (SVC), and Generalized UPFC (GUPFC), along with AI-based techniques like the Unified Power Quality Conditioner (UPQC)-FLC and Fuzzy Logic Controller (FLC)-UPFC. Furthermore, EVs are a crucial part of the power grid, but they are moving away from RES because to the risks as well as limitations of RES and ESS. Therefore, it is essential to pay attention to enhancing the power quality of the PV-WE-ESS-EV system that is connected to the grid. This needs to be researched and validated using the available methods to power quality enhancement.

In the past three decades, there has been an elevation in the electricity generation from conventional energy sources, and among all of them, wind energy is mainly thought to be employed in situations where the necessary solar energy is not available. According to **J. Sandhya [11]**, the primary benefits of utilizing wind as an energy source are a decrease in the fossil fuels consumption, a reduction in greenhouse gas emissions, as well as decline in the energy production cost, along with the usage of a clean, natural energy source. They are aware that wind speed varies widely, making it challenging to incorporate wind energy into current power systems due to problems with security, reliability, availability, and the quality of the electricity that must be provided to the grid or the load center. The UPQC circuit model was developed in this study for the power quality enhancement in grid-connected wind systems, and results were compared with STATCOM by running the model in the MATLAB/Simulink program. Simulations enable the observation of WECS output with and without a controller.

According to **Shubh Lakshmi [12]**,for increasing energy efficiency and PQ, the study provides a modeling and allocation technique for an integrated photovoltaic (PV) generation system that is part of an open, unified power quality conditioner (UPQC-O) radial distribution network. Series and shunt inverters make up a UPQC, a unique power component. These inverters are distributed throughout a network according to UPQC-O. These inverters may communicate with one another to share information and choose the appropriate set point. Two variations have been proposed: (i) the UPQC-O with PV array only (UPQC-O-WOB), and (ii) the UPQC-O with battery and PV array (UPQC-O-WB). The energy that is produced by the solar panels in UPQC-O-WB is stored while they are operational so that it can be used during peak hours. However, with UPQC-O-WOB, the network is immediately supplied with the energy generated by the PV array. The forward-backward sweep load flow incorporates the proposed models to figure out operating characteristics such bus voltage. To find the best location for UPQC-O with PV array in distribution networks, an optimization problem gets formulated. The objective function incorporates the expenses associated with purchasing and maintaining inverters, batteries, and PV arrays, as well as the cost of energy loss. The chosen approach for finding a solution is particle swarm optimization.

4. Methodology

The MATLAB/SIMULINK Platform has been used to analyze the DG_UPQC designing. The modeling process entails developing the DG_UPQC's fundamental structure and controlling it through vector modulation.

A unified power quality conditioner's equivalent circuit diagram is depicted in Figure The supply voltage is 2 Vs, the series and shunt compensation voltages and currents are V_{ac} and I_{ac}, and the load voltage and current are V_{load} and I_{load}, respectively. The source voltage may have harmonic, zero, and negative components. The system's per phase voltage can be stated as

$$V_a = V_{1pa} + V_{1na} + V_{10a} + \sum_{k=2}^{\infty} V_{Ka} \sin(k\omega t + \theta_{Ka}) \quad (1)$$

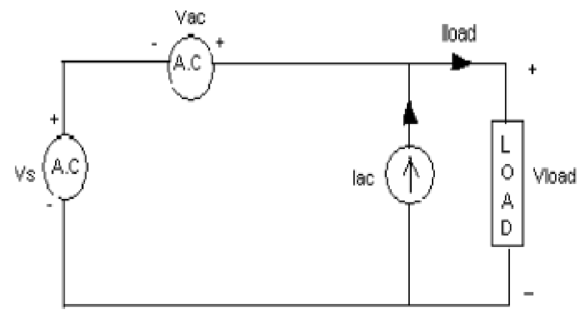

Figure 2: Basic Circuit Configuration of the Unified Power Flow Controller.

where V_{1pa} is the fundamental frequency's positive sequence component, V_{1na} is its negative sequence component, and V_{10a} is its zero sequence component. The final component of the equation stands in for the voltage's harmonic content. The series filter should provide a value of in order to ensure that the load voltage is completely sinusoidal and balanced.

$$V_{ah} = V_{1na} + V_{10a} + \sum_{k=2}^{\infty} V_{Ka} \sin(k\omega t + \theta_{Ka}) \quad (2)$$

The shunt active filter's duties include maintaining a constant DC link current, adjusting for load harmonic current, and reducing reactive power usage. The load current per phase of the shunt active filter is written as

$$i_{al} = I_{1pm} \cos(\omega t - \theta_1) + I_{a\,ln} + \sum_{k=2}^{\infty} i_{alk} = I_{ipm} \cos \omega t \cos \theta_1 + I_{1\,pm} \sin \omega t \sin \theta_1 + I_{a\,ln} + \sum_{k=2}^{\infty} i_{alk} \quad (3)$$

The shunt active filter should produce a current that accounts for harmonic current and reactive power consumption.

$$I_{ah} = I_{1\,pm} \sin \omega t \sin \theta_1 + I_{a\,ln} + \sum_{k=2}^{\infty} i_{alk} \quad (4)$$

thereby ensuring that the source current will

$$i_{as} = i_{al} - i_{ah} = I_{1\,pm} \cos \omega t \cos \theta_1 \quad (5)$$

This sinusoidal current is in phase with the voltage and has perfect harmonics. Similar voltage equations can be used in the system to reduce harmonics.

Table 1 Voltage relationships in each of the six sectors which comprise the reference vectors.

Sectors	Phase Voltage A	Phase Voltage B	Phase Voltage C
A	U_a	U_b	U_c
B	$-U_b$	$-U_c$	$-U_a$

C	U_c	U_a	U_b
D	$-U_a$	$-U_b$	$-U_c$
E	U_b	U_c	U_a
F	$-U_c$	$-U_a$	$-U_b$

To mitigate reactive and harmonic currents brought on by the load, the parallel converter is controlled as a current source. The control mechanism is applied to the synchronous rotating dq frame.

The Quality Control Evolutionary Strategy is a population-based heuristic technique to resolve continuous-space global optimization problems with different properties.

Despite being simple, it excelled in addressing non-continuous, non-differentiable, as well as multi-modal optimization issues. In the simple QC_ES, ES/rand/1/bin algorithm, a uniform distribution inside the lower and upper boundaries (x_j^L,x_j^U) has been utilized to generate a random initial population of NP individuals ($\overrightarrow{X_j}$), where j=1, 2..., NP, and so on. To evolve individuals and produce a trial vector, crossover and mutation are used. To determine who will generate the most offspring that are the fittest, the trial vector competes with his parent.

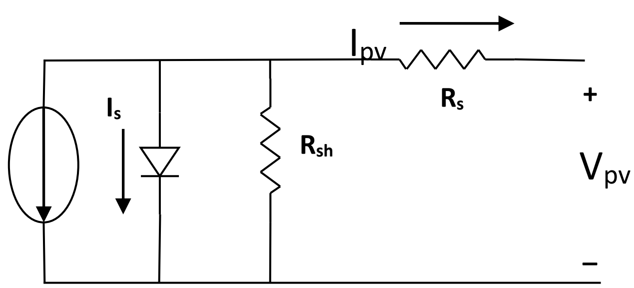

Figure 3: Equivalent circuit of solar PV cell

The solar induced current of a solar PV cell, which depends on the amount of solar radiation and the operating temperature, may be expressed as follows:

$$I_{ph} = I_{sc} - k_i(T_c - T_r) * \frac{I_r}{1000} \quad (6)$$

Where:

T_C ,T_r Cell working and reference temperature at STC

k_iCellshort-circuit current/temperature coefficient(A/K)

I_{SC}Short-circuit current of cell at STC

I_r Irradiance in w/m

5. Result

A versatile instrument known as a unified power quality conditioner, lowers voltage disturbances on the grid side and current disturbances on the load side at the same time. The DC link, which connects the DG sources in a directly linked UPQC-DG, delivers both the active power needed by the load through the parallel converter and the active power needed by the series converter for grid voltage correction.

Utilizing the Sim Power System Toolbox, the simulation model is created in the MATLABSIMULINK environment. Under typical unbalanced loads and nonlinear loading circumstances, the DG_UPQC's performance is observed. It is assumed that the system line voltage is 400V. Two systems' DG¬_UPQC simulation results as harmonic compensators are examined.

System 1: DG_UPQC with vector modulation control having PI regulators and voltage regulation technique

System 2: DG_UPQC with AI based switching modulation with having quality controlled evolution strategy QC_ES for the power system.

Case 1: Analysis of Voltage Current and Power Quality in the system 1 driving various loads

The line that the DG_UPQC is linked to also has a DC link that receives power from two hybrid renewable energy sources. The converter at the load end has been fed PWM signals whose reference is provided by a PI-based control system, and the analysis has been done at loading points, in order to reduce the effects of fluctuating inputs to these sources of energy into the line.

The nonlinear load terminal has been taken into account during analysis.

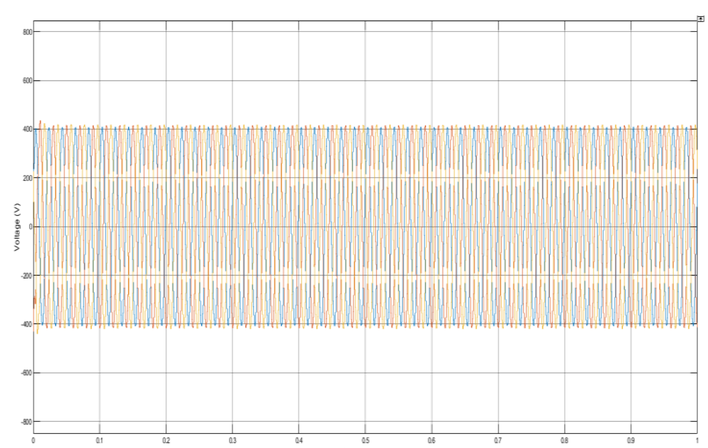

Figure 4: Three phase voltage available at the loading point of nonlinear load in system 1

Three phase voltage output available at the loading points is depicted in figure. The phase to phase voltage is approximately 400V in system 1.

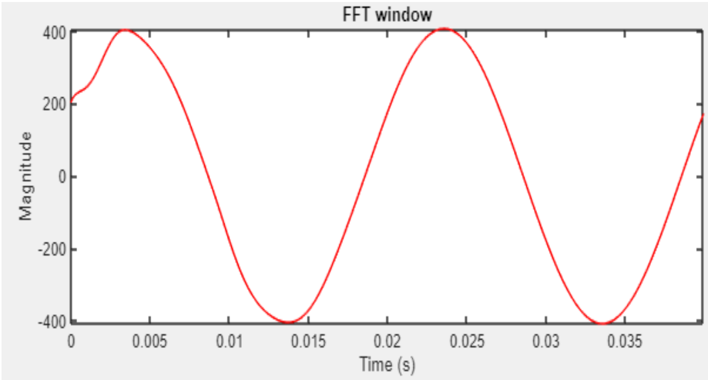

Figure 5:FFT analysis MATLAB window of voltage available at the loading point of nonlinear load in system 1

Figure illustrates the FFT analysis of system 1's voltage output. This is further utilized to evaluate the harmonic content in thee phase output voltage.

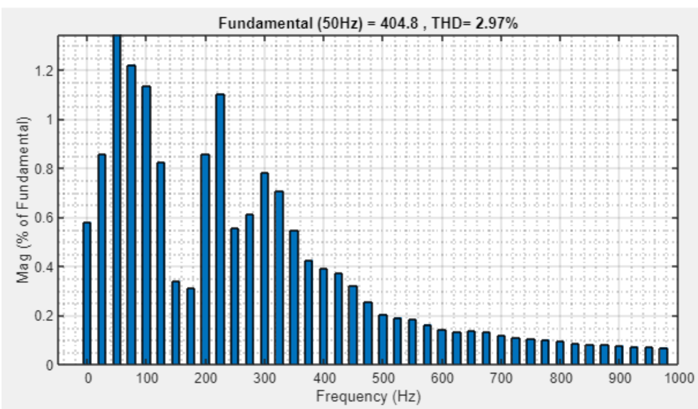

Figure 6:THD% in voltage available at the loading point of nonlinear load in system 1

The figure represents the THD% evaluation in the system 1 line voltage available at the nonlinear loading point that came out to be 2.97% when the DG_UPQC is driven by the vector based PI regulation method of the control system.

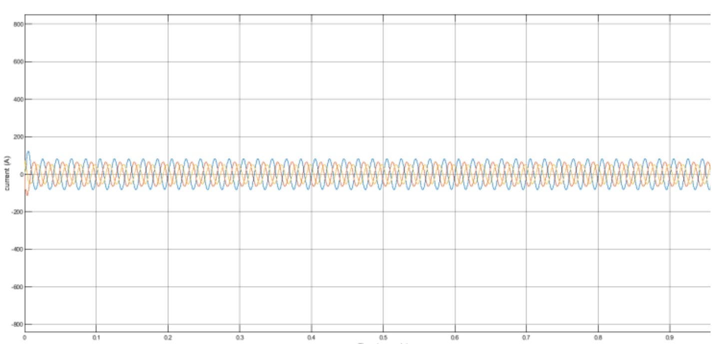

Figure 7: Three phase current drawn at the nonlinear load's loading point in system 1

Three phase current at the loading points of the nonlinear load terminal is depicted in figure. The current drawn is approximately 60 A in system 1.

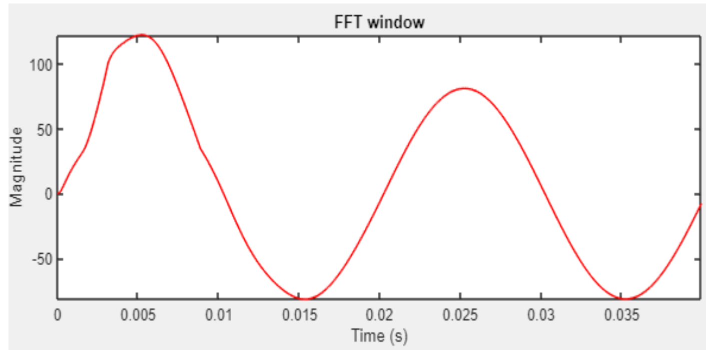

Figure 8:FFT analysis MATLAB window of current drawn at the loading point of nonlinear load in system 1

The FFT analysis of the current flowing via System 1's nonlinear load terminal point is depicted in Figure. This is further utilized to evaluate the harmonic content in thee phase output current.

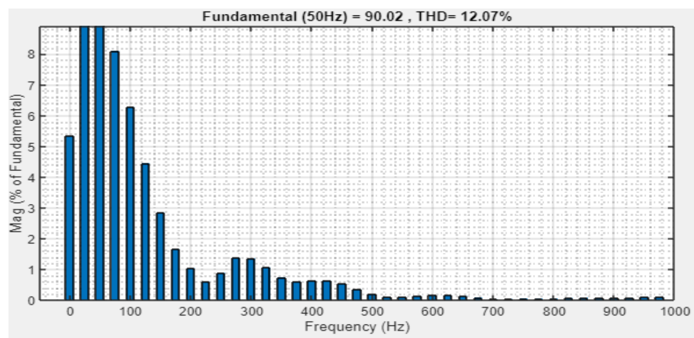

Figure 9:THD% in current drawn at the loading point of nonlinear load in system 1

The figure represents the THD% evaluation in the system 1 line current at the nonlinear loading point that came out to be 12.07% when the DG_UPQC is driven by the vector based PI regulation method of the control system.

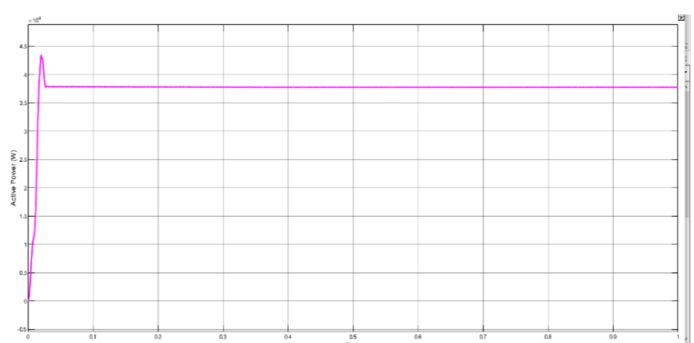

Figure 10: Active Power output in the line at the loading point of nonlinear load in system 1

The available active power output from the system 1 which carries DG_UPQC controlled vector modulation control having PI regulators and voltage regulation technique is represented in figure. The output power came to be approximately 37780 W

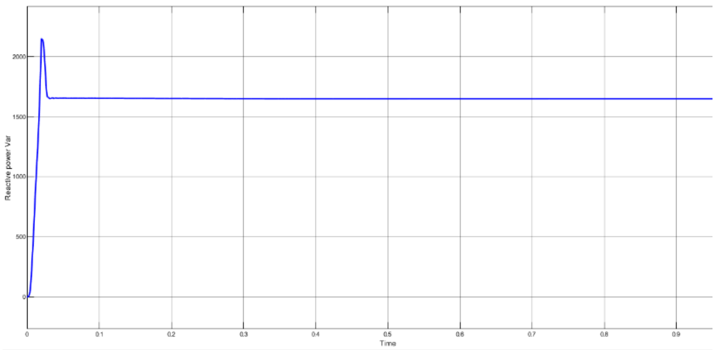

Figure 11: Reactive Power output in the line at the loading point of nonlinear load in system 1

The available reactive power output from the system 1 which carries DG_UPQC controlled vector modulation control having PI regulators and voltage regulation technique is represented in figure. The power after compensation came to be approximately $1649V_{ar}$.

Case 2: Analysis of Voltage Current and Power Quality in the system 2 driving various loads

Both the designs of DG_UPQC controllers are subjected to nonlinear loads and its quality analysis while driving these loads is done in terms of distortion evaluation in the voltage and current. To mitigate the effects of variable inputs to these sources of energy into the line the converter at the load end has been fed PWM signals whose reference is generated by AI based switching modulation with having quality controlled evolution strategy QC_ES system and the analysis has been carried out at loading points. The effects are studied for the compensation capabilities of the designed UPQC structure with DC link maintained by hybrid resources.The study is then expanded to evaluate the total harmonic distortion present in the system for both the current and voltage waveforms available at the system's loading points.

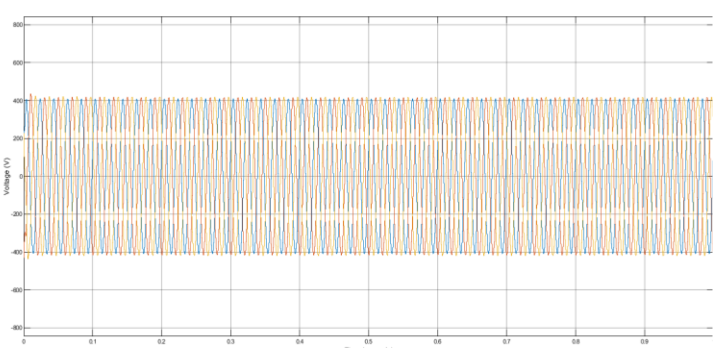

Figure 12: Three phase voltage available at the loading point of nonlinear load in system 2

Three phase voltage output available at the loading points is depicted in figure. The phase to phase voltage is approximately 400V in system 2.

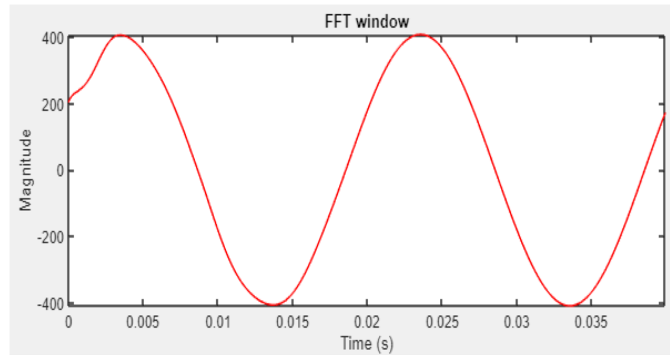

Figure 13:FFT analysis MATLAB window of voltage in line at the loading point of nonlinear load in system 2

Figure represents the voltage output's FFT analysis in system 2. This is further utilized to evaluate the harmonic content in thee phase output voltage

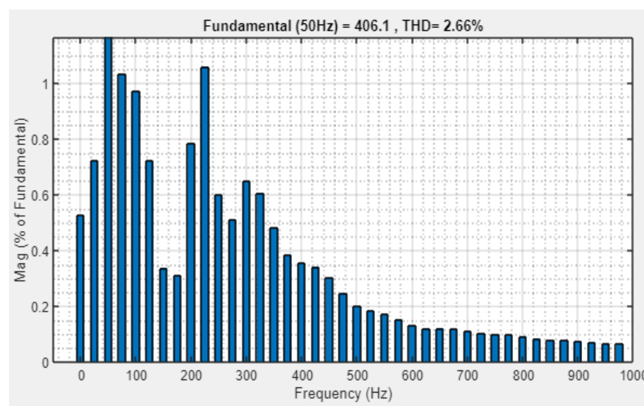

Figure 14:THD% in voltage at the loading point of nonlinear load in system 2

Figure represents the THD% evaluation in system 1 line voltage available at the nonlinear loading point that came out to be 2.66% when the DG_UPQC is driven by the vector based PI regulation method of the control system.

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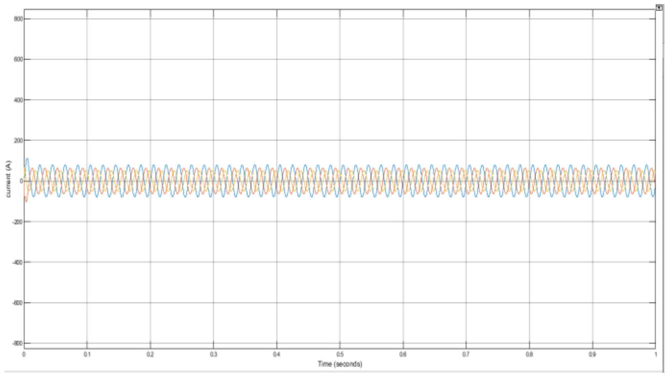

Figure 15: Three phase current drawn at the loading point of nonlinear load in system 2

Three phase current at the loading points of the nonlinear load terminal is depicted in figure 5.12 for the system 2 where DG_UPQC is driven by the proposed I based technique

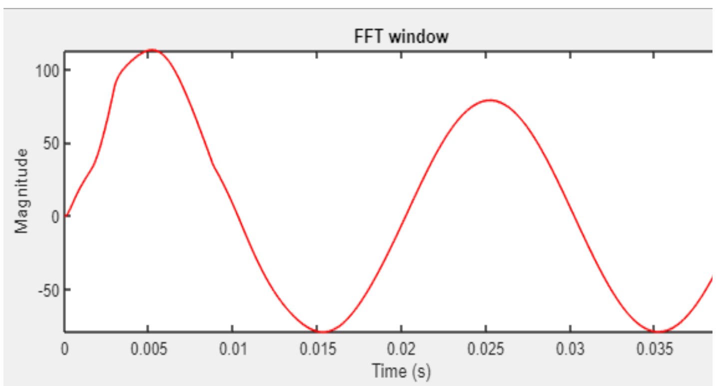

Figure 16:FFT analysis MATLAB window of current drawn at the loading point of nonlinear load in system 2

Figure represents the FFT analysis of the current drawn in the nonlinear load terminal point in system 2. This is further utilized to evaluate the harmonic content in thee phase output current for system 2 at the loading point

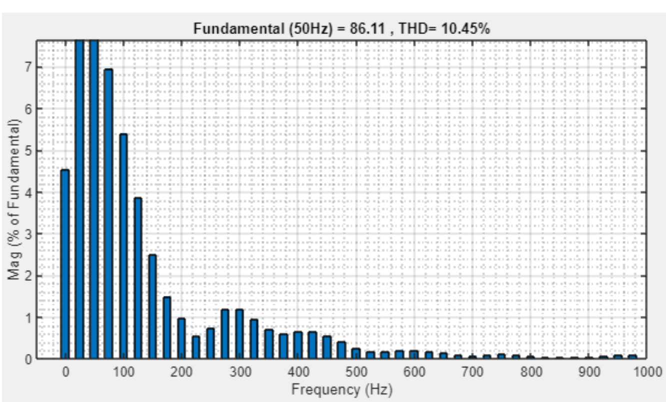

Figure 17:THD% in current drawn at the loading point of nonlinear load in system 2

The figure represents the THD% evaluation in the system2 line current available at the nonlinear loading point that came out to be 10.45% when the DG_UPQC is driven by the AI based switching modulation with having quality controlled evolution strategy QC_ES method of the control system.

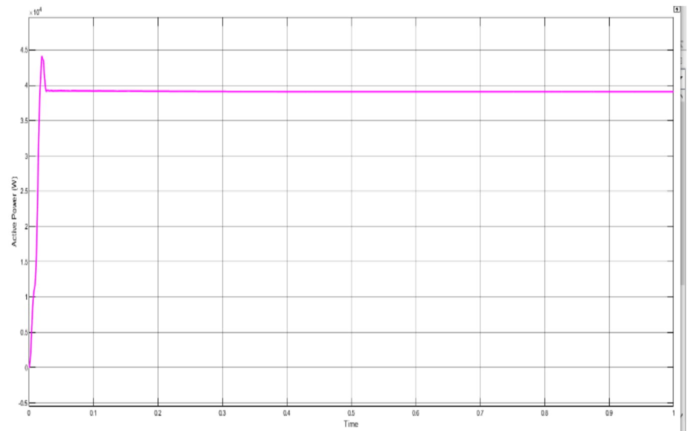

Figure 18: Active Power output in the line at the loading point of nonlinear load in system 2

The available active power output from the system 2 which carries DG_UPQC controlled by AI based switching modulation with having quality controlled evolution strategy QC_ES is represented in figure. The output power came to be approximately 39110 W

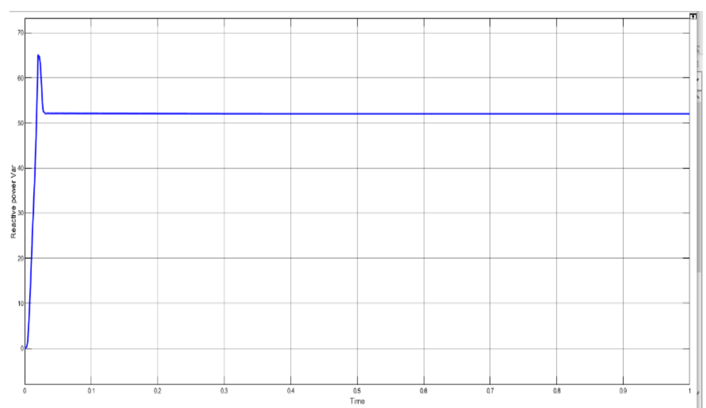

Figure 19: Reactive Power output in the line at the loading point of nonlinear load in system 2

The available reactive power output from the system 2 which carries DG_UPQC controlled by AI based switching modulation with having quality controlled evolution strategy QC_ES is represented in figure. The power after compensation came to be approximately 52.85 Var.

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Table 2: Comparative analysis of DG_UPQC with converters driven by different controlling algorithms

Parameters	**System 1**	**System 2**
Voltage (Volts)	400	
Active Power (W)	37780	39110
Power Factor Correction	0.91	0.96
Reactive Power (Var)	1649	52.85
Quality analysis at the loading points of nonlinear load		
Load voltage (THD%)	2.97 %	2.66%
Load current (THD%)	12.07%	12.45%

Analysis of the two DG_UPQC at the unbalanced terminal of load (Local loads)

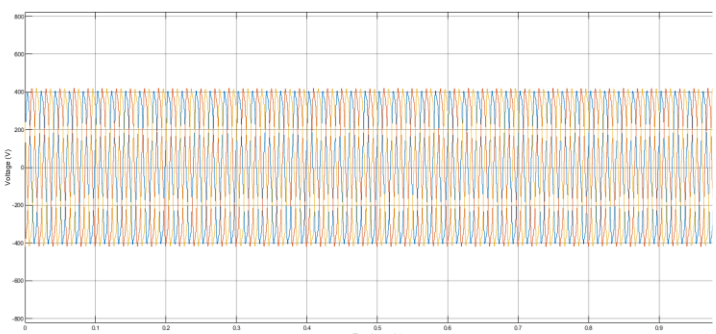

Figure 20: Voltage injected by the DG_UPQC at the unbalanced load terminal in system 1

Three phase voltage output available at the loading points where unbalanced load is connected is depicted in figure. The phase to phase voltage is same for all phases which is approximately 400V in system 1.

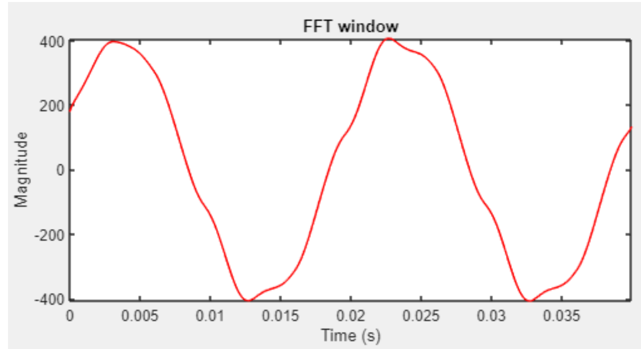

Figure 21:FFT analysis of the Voltage injected in line by the DG_UPQC at the unbalanced load terminal in system 1

Figure represents the FFT analysis of the voltage output in system 1. This is further utilized to evaluate the harmonic content in thee phase output voltage

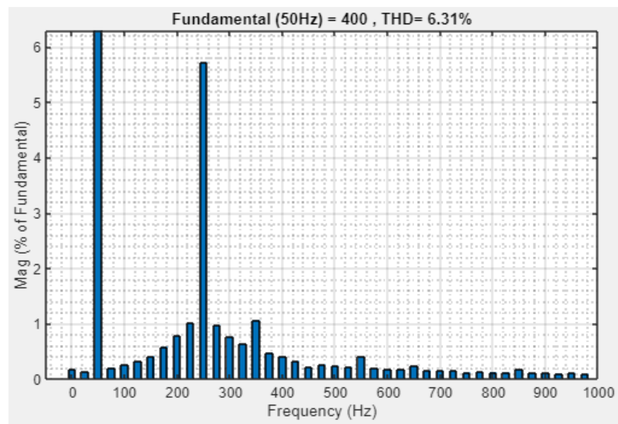

Figure 22:THD % in the Voltage injected in line by the DG_UPQC at the unbalanced load terminal in system 1

The figure represents the THD% evaluation in the system 1 line voltage available at the unbalanced loading point that came out to be 6.31% when the DG_UPQC is driven by the vector based PI regulation method of the control system

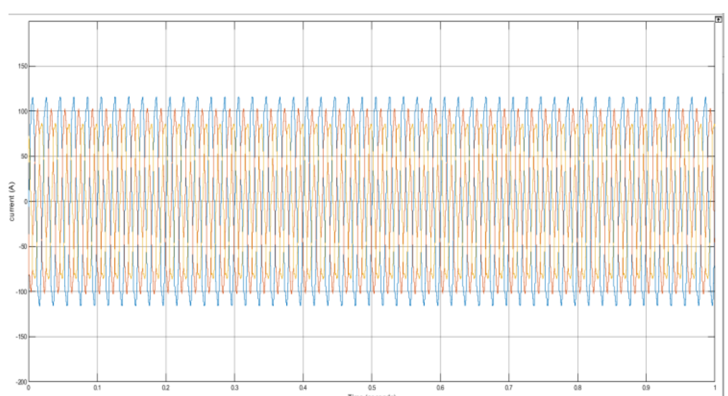

Figure 23: Current drawn at the unbalanced load terminal in system 1

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Three phase current at the loading points of the unbalanced load terminal of system 1 is depicted in figure. The current drawn is different for all the phases.

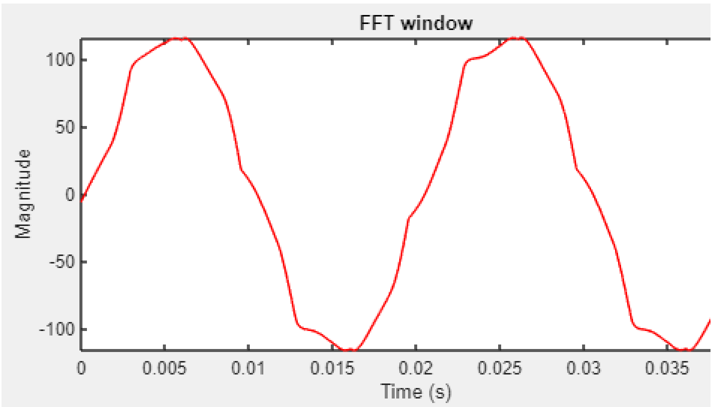

Figure 24:FFT analysis of Current drawn at the unbalanced load terminal in system 1

Figure represents the FFT analysis of the current drawn in an unbalanced load terminal point in system 1. This is further utilized to evaluate the harmonic content in thee phase output current

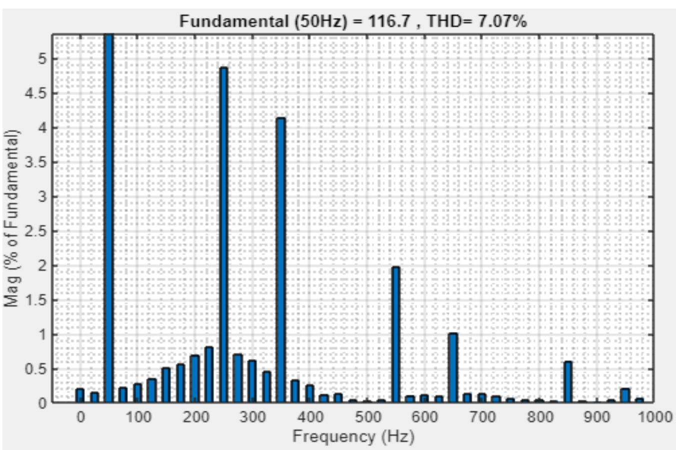

Figure 25:THD% in Current drawn at the unbalanced load terminal in system 1

The figure represents the THD% evaluation in the system 1 line current at the unbalanced loading point that came out to be 7.07% when the DG_UPQC is driven by the vector based PI regulation method of the control system.

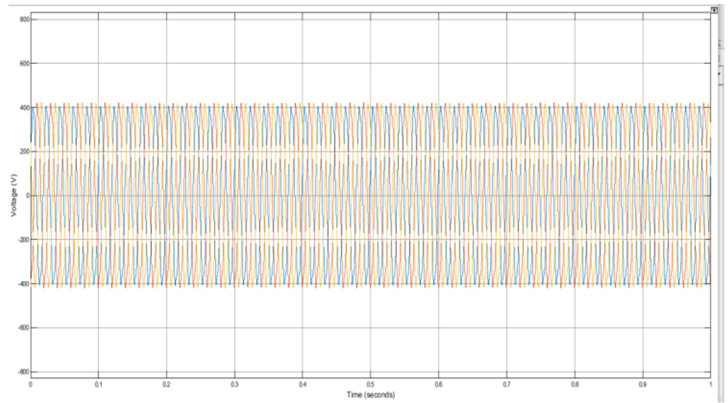

Figure 26: Voltage injected in line by the DG_UPQC at the unbalanced load terminal in system 2

Three phase voltage output available at the loading points where unbalanced load is connected is depicted in figure. The phase to phase voltage is same for all phases which is approximately 400V in system 2.

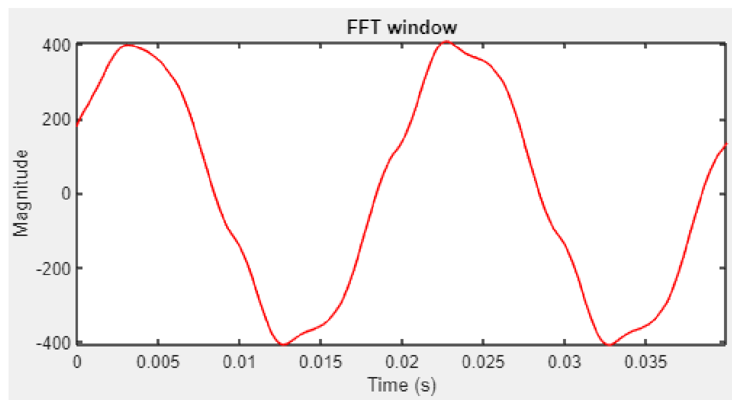

Figure 27:FFT analysis of Voltage injected in line by the DG_UPQC at the unbalanced load terminal in system 2

Figure represents the FFT analysis of the voltage output in system 2. This is further utilized to evaluate the harmonic content in thee phase output voltage

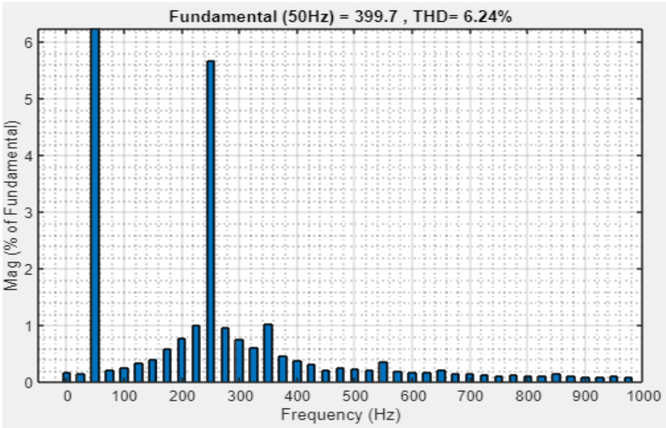

Figure 28:THD% in Voltage injected in line by the DG_UPQC at the unbalanced load terminal in system 2

The figure represents the THD% evaluation in the system 2 line voltage available at the nonlinear loading point that came out to be 6.24% when the DG_UPQC is driven by AI based switching modulation with having quality controlled evolution strategy QC_ES **.**

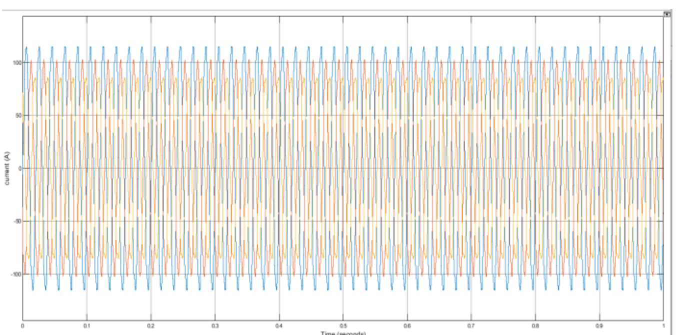

Figure 29: Current drawn at the unbalanced load terminal in system 2

Three phase current at the loading points of the unbalanced load terminal of system 2 has been depicted in figure. The current drawn is different for all the phases.

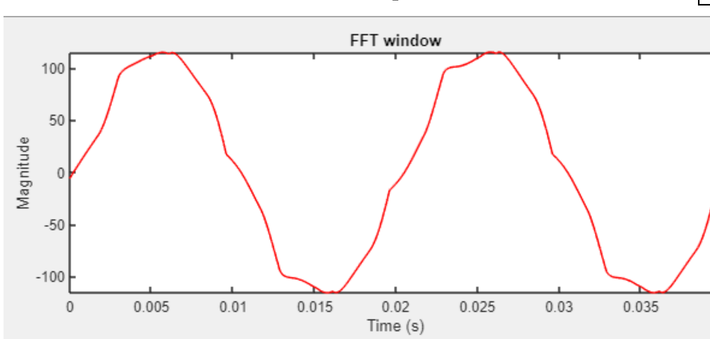

Figure 30:FFT analysis of Current drawn at the unbalanced load terminal in system 2

Figure represents the FFT analysis of the current drawn in the unbalanced load terminal point in system 2. This is further utilized to evaluate the harmonic content in thee phase output current

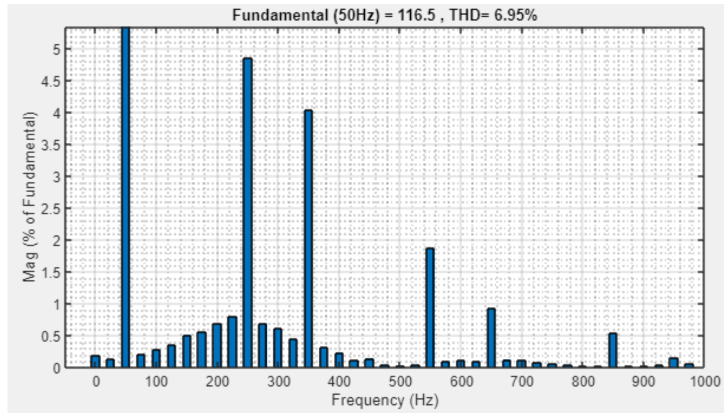

Figure 31 THD% in the Current drawn at the unbalanced load terminal in system 2

The figure represents the THD% evaluation in the system 2 line current at the unbalanced loading point that came out to be 6.95% when the DG_UPQC is driven AI based switching modulation with having quality controlled evolution strategy QC_ES.

Table 3: Comparative analysis of DG_UPQC with converters driven by different controlling algorithms at the unbalanced terminals

System Parameters	System 1	System 2
THD% in load voltage	6.31 %	6.24%
THD% in load current	7.07%	6.95%

6. Conclusion

The work led to the significant findings listed below:

- The power outcomes were enhanced from 37780 watts to 39110 watts, resulting in a 3.5% improvement in the active power and a decrease in reactive power to 52.85 Var in the suggested system. This led to enhancement in the system power factor from 0.91 to 0.96
- THD% reduce during the analysis in both voltage and current waveforms. The THD% evaluated in system 1 for voltage having the DG_UPQC controlled vector modulation control having PI regulators and voltage regulation technique had 2.97% and 6.31% distortion at different loading points.

- The THD% evaluated of voltage in system 2 having controlled by AI based switching modulation with having QC_ES had 2.66% and 6.24% distortion at different loading points.
- The THD% evaluated in system 1 for current output having the DG_UPQC controlled vector modulation control having PI regulators and voltage regulation technique had 12.45% and 7.07% distortion at different loading points.
- The THD% evaluated of current in system 2 having controlled by AI based switching modulation with having QC_ES had 10.45% and 6.95% distortion at different loading points.

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