http://doi.org/10.35784/iapgos.5445 *received: 09.10.2023 | revised: 26.02.2024 | accepted: 09.03.2024 | available online: 31.03.2024*

THE IMPACT OF LIGHTNING STRIKE ON HYBRID HIGH VOLTAGE OVERHEAD TRANSMISSION LINE – INSULATED GAS LINE

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Abstract. *The electrical network is the set of elements where loads are connected to the generation plants by transmission lines. They can be either overhead or underground cables. A new technology has been introduced to replace these transmission lines with underground cables gas insulated line "GIL". The latest has many advantages over underground cables and overhead transmission lines, such as low transmission losses, less capacitive load, reliability, personal safety, same operation as overhead lines and negligible electrical aging. GIL can handle much more power than overhead lines due to its large conductive area. GIL is the best for high voltage. In this paper, the simulation of lightning strike effects on a 400 kV hybrid transmission line located in the Wilaya of Setif in northern Algeria is presented in the absence and presence of line arresters and GIL arresters. The results of this paper can provide a rich and valuable theoretical reference for GIL simulation modeling and evaluation of lightning strike impact on hybrid overhead – GIL lines.*

Keywords: overhead transmission line, gas insulated line, lightning strike, surge arrester

WPŁYW UDERZENIA PIORUNA NA HYBRYDOWĄ LINIĘ WYSOKIEGO NAPIĘCIA NAPOWIETRZNA LINIA PRZESYŁOWA – IZOLOWANA LINIA GAZOWA

Streszczenie. *Sieć elektryczna to zbiór elementów, w których obciążenia są połączone z elektrowniami za pomocą linii przesyłowych. Mogą to być linie napowietrzne lub podziemne. Nowa technologia została wprowadzona w celu zastąpienia tych linii przesyłowych podziemnymi kablami w izolacji gazowej "GIL". Najnowsza technologia ma wiele zalet w porównaniu z kablami podziemnymi i napowietrznymi liniami przesyłowymi, takich jak niskie straty przesyłowe, mniejsze obciążenie pojemnościowe, niezawodność, bezpieczeństwo obsługi, takie samo działanie jak w przypadku linii napowietrznych i znikome starzenie elektryczne. GIL może obsługiwać znacznie większą moc niż linie napowietrzne ze względu na dużą powierzchnię przewodzącą. GIL jest najlepszy dla wysokich napięć. W niniejszym artykule przedstawiono symulację skutków uderzenia pioruna w hybrydową linię przesyłową 400 kV zlokalizowaną w Wilaya, Setif w północnej Algierii w przypadku braku i obecności ograniczników liniowych i ograniczników GIL. Wyniki tego artykułu mogą stanowić bogate i cenne teoretyczne odniesienie do modelowania symulacji GIL i oceny wpływu uderzenia pioruna na hybrydowe linie napowietrzne – GIL.*

Słowa kluczowe: napowietrzna linia przesyłowa, linia w izolacji gazowej, uderzenie pioruna, ogranicznik przepięć

Introduction

Compared to traditional bare wire and cable, the cost of GIL is relatively high. However, the cost of geothermal cables is decreasing as the technology of production processes improves. In the context of today's ubiquitous smart grid and the global energy Internet of energy, the requirements for transmission and transmission of various links are becoming increasingly high, and the application of GIL is becoming increasingly broad. The global transmission and distribution giants have invested in GIL research [18]. Due to its special structure and excellent performance, GIL is used in some power plants or large hub power plants, where the installation method is special and the safety requirements are high. In the future, with the development of technology, it will be applied to long distance transmission. However, due to its cost and other reasons, GIL has not been widely promoted. Currently, the GIL lines used in the world have reached thousands of kilometers [11]. Several recent researches have invested in the study and simulation of different combinations of hybrid lines, in [3] the authors have studied the scheme design of integrated grounding system for a 550 kV gas insulated transmission line, researchers in [12] have presented a short circuit current calculation of EHV overhead Line-GIL hybrid line, in [25] authors proposed a novel light weight 2D multi-slice electromagnetic field-circuit coupled method for computing transient electromagnetic force. In reference [4], researchers studied The induced voltage and current for hybrid transmission system.

In high voltage systems, the protection and reliability of these elements plays an important role in the analysis and simulation of these systems because of the danger that can be caused by the shock wave of a direct lightning strike on the line or a short circuit, an overload, etc.

Researchers in [22], have studied the holistic modelling of 500 kV GIS step-up substation equipment with a double circuit and long GIS busbar in a coastal power plant is established using Electromagnetic Transient Program. In [6], the FEA method is used for insulation design of multi-conductor transmission lines. In the design of -800 kV transmission line, coaxial and non-coaxial structures are mainly considered. The purpose of our article is to investigate the influence of lightning arresters on the evolution of voltages and currents on a three-phase hybrid line impacted by a direct lightning strike on one phase of a tower located in the middle of the line.

1. Components of the system to be studied

1.1. Surge arrester

A surge arrester is a protective device used to protect electrical equipment from damage due to lightning surges or other transients in electrical power systems. In the case of lightning surges, a surge arrester provides a low-impedance path for the surge current to flow to ground, thus limiting the voltage applied to the protected equipment and preventing damage [14].

Figure 1, illustrate some examples of line arrester hung on tower arms.

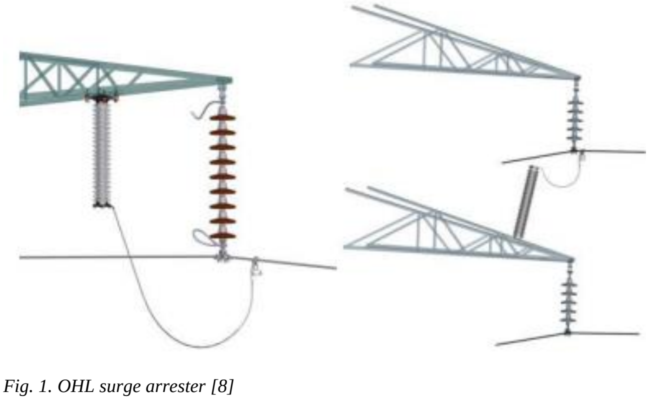


Fig. 1. OHL surge arrester [8]

Surge arresters typically consist of a nonlinear resistor (such as a metal oxide varistor) connected in parallel with the protected equipment, with a low impedance path to ground. When a lightning surge or other transient occurs, the voltage across the surge arrester exceeds its breakover voltage, causing the nonlinear resistor to rapidly conduct the surge current to ground. There are different types of surge arresters available for different applications, including overhead line arresters, distribution arresters, and low-voltage arresters [8, 9].

1.2. Lightning strike

A lightning strike is a sudden and powerful discharge of electricity from the atmosphere to the ground or another object, caused by the buildup of electrical charge in thunderstorms. Lightning strikes can cause significant damage to electrical equipment and infrastructure, and can also be a significant hazard to people and animals. Lightning is a complex phenomenon that is still not fully understood, but it is thought to be caused by the buildup of electrical charge in thunderstorms. When the electric field within a thunderstorm becomes strong enough, it can ionize the air, creating a path for the electrical discharge to flow. The resulting lightning strike can transfer tens of thousands of amperes of current to the ground in a fraction of a second, creating a high-voltage, high-frequency electrical surge [17, 24].

Lightning strikes can cause a variety of effects, depending on the magnitude of the strike and the proximity to the target. For example, a direct lightning strike can cause fire, explosion, or structural damage, while a nearby lightning strike can cause electromagnetic interference (EMI) or electrical surges that can damage sensitive electronic equipment [17].

Due to the dangerous effects of lightning strikes on property and people, a recent study is published which gives the detection of lightning has arrived thanks to the space-based operational lightning imagers [1].

1.2.1. Overhead line

An overhead line, also known as an overhead power line or overhead transmission line, is a system of electrical conductors used to transmit high-voltage electricity from power plants to distribution substations or directly to large industrial customers. The conductors are typically supported by tall steel or concrete poles, or towers, and are usually made of aluminium or copper. Overhead lines are widely used in power transmission and distribution because they are relatively inexpensive and have lower electrical losses compared to underground cables. However, they can be vulnerable to weather-related disruptions such as high winds, lightning, and ice accumulation [11–13, 15–20].

1.2.2. Gas insulated line GIL

Gas Insulated Line (GIL) is a type of high-voltage power transmission system that uses a gas-insulated conductor to transmit electricity over long distances. The GIL consists of a metal housing or tube that contains one or more conductors, which are insulated by a compressed gas, typically sulphur hexafluoride (SF6). The gas provides excellent electrical insulation and allows the GIL to operate at high voltages without the risk of electric breakdown. GIL is typically used for underground and underwater transmission lines, where it can offer higher power density, greater reliability, and lower environmental impact compared to traditional overhead power lines or underground cables. However, GIL systems can be expensive to install and maintain, and there are concerns about the environmental impact of SF6 gas, which is a potent greenhouse gas [4, 9, 20–23]. The basic structure of 500 kV GIL is illustrated in figure 2, it is mainly composed of metal enclosure, inner conductor, post insulator, basin insulator and particle trap [16].

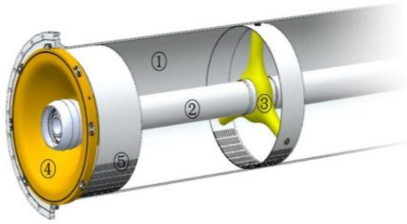


Fig. 2. Basic structure of gas insulated transmission line (GIL) [16]

2. Simulation models

EMTP-ATP software is used to modelling and simulation, Electromagnetic Transients Program is a software tool used by power systems engineers to analyse electromagnetic transients and associated insulation issues, it is developed by Dr. Scott Meyer and co. in USA. The used models of the OHL line and these components have been developed in [5, 21]. The surge arresters were represented by the Pinceti and Giannettoni frequency-dependent model [1, 2, 5, 7, 10, 14] as shown in Fig. 3.

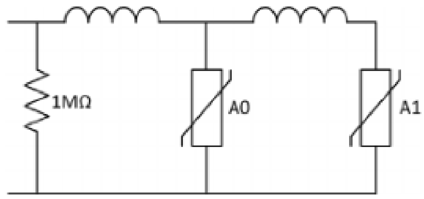


Fig. 3. Frequency-dependent surge arrester model, with: $R = 1\ M\Omega$, $L_0 = 4.5\ \mu H$, $L_1 = 13.6\ \mu H$

3. Power system description

The OAT-El Hassi line (400 kV) located in the north east of Algeria in the Wilaya of Setif. The line is divided into a number of identical sections as shown in figure 4 for the 400 kV line. Authors chose a length of portion equal to 2.4 km divided into 10 spans (Fig. 4). GIL is located in the middle of the OHL line, it is of length of 2 km, two identical surge arresters have been placed upstream and downstream of GIL in order to compare the simulation results obtained in presence and absence of the GIL arresters, a direct lightning strike is introduced on the ground wire of the first tower (Tower 1) of power system presented in figure 4.

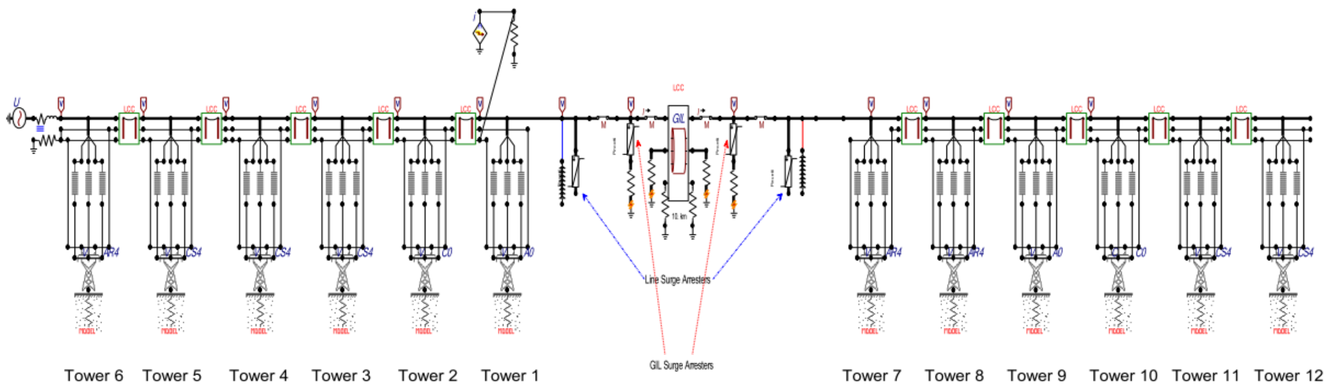


Fig. 4. Study power system

In this study, a positive polarity of lightning current is used to perform shielding failure pattern analysis on the modelled circuit. Simulations are thus conducted with a lightning-strike, the characteristics given on the table 1. Authors in the reference [2] have detailed the calculation of the GIS simulation parameters in the EMTP-ATP software such as the grounding grid resistance, grounding strip inductance and grounding strip resistance.

Table 1. Characteristics of lightning strike

Front time (µs)	2	2	2	2
Tail time (µs)	30	70	180	260
Lightning current amplitude, kA	120	120	120	120

4. Simulation results

If the grounding wire is properly installed and connected, it can provide a path for the lightning to discharge safely into the ground. In this case, the lightning strike may cause a surge in the electrical system, but the surge protectors and other safety devices in the electrical system should be able to handle the surge and protect the appliances and other devices connected to the system.

In this context, our research is based on the role of lightning arrestors in hybrid high voltage transmission lines; The impact of a series of lightning strikes of amplitude 120 kA with different tail times is simulated. In figure 5, the magnitude of lightning current for a time simulation 50 µs is plotted.

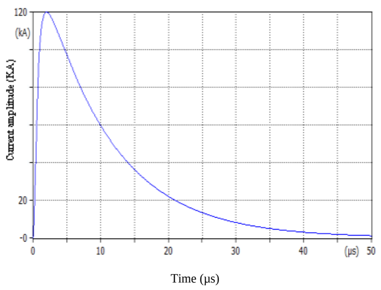


Fig. 5. Lightning strike current amplitude

The induced voltage in the A phase of the transmission line is simulated in five different cases configuration with different combinations of line and GILs arresters.

Case 1: OHL with surge arrester line, without GIL.

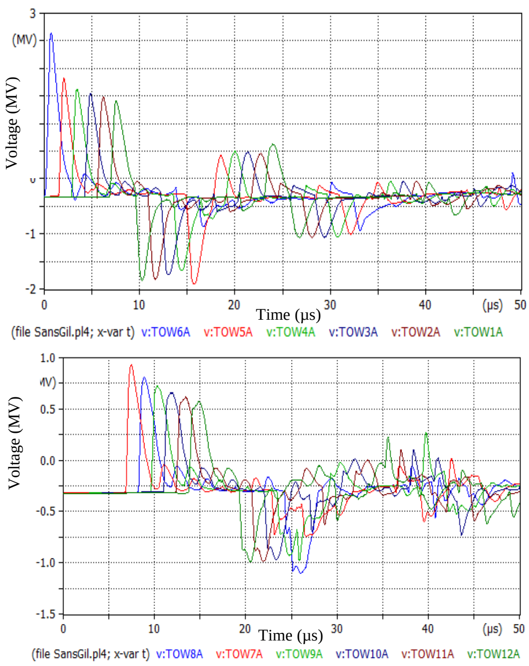


Fig. 6. Induced voltage across the phase conductor "A" (case 1): a) voltage evolution in tower 6, 5, 4, 3, 2, and 1, b) voltage evolution in tower 7, 8, 9, 10, 11, and 12

Case 2: Hybrid OHL with surge arrester line, without GIL surge arrester.

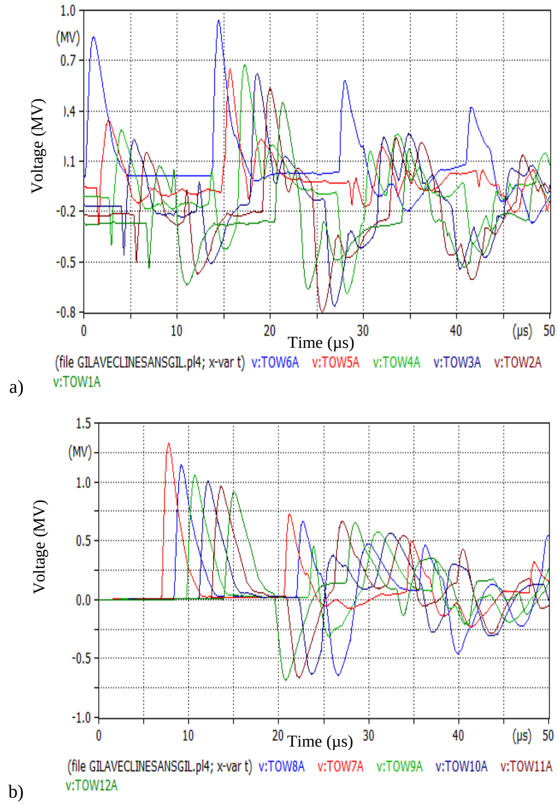


Fig. 7. Induced voltage across the phase conductor "A" (case 2): a) voltage evolution in tower 6, 5, 4, 3, 2, and 1, b) voltage evolution in tower 7, 8, 9, 10, 11, and 12

Case 3: Hybrid OHL without surge arrester line, without GIL surge arrester.

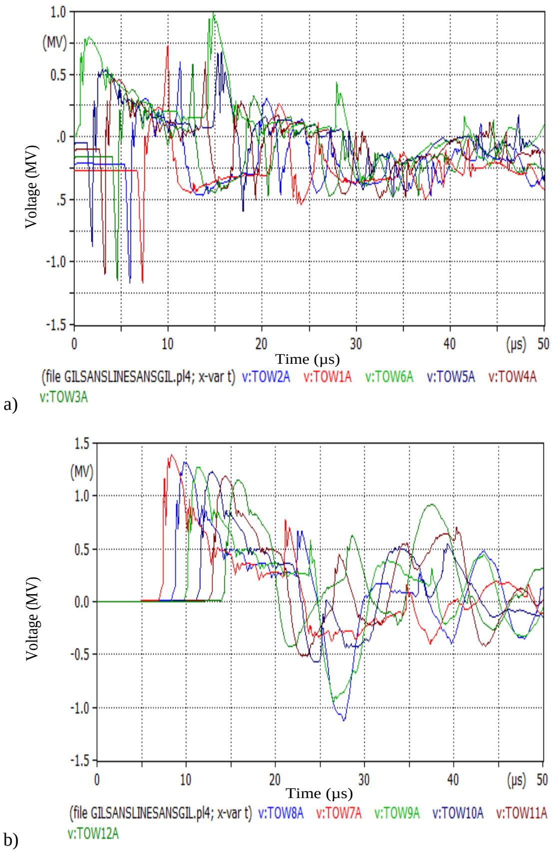
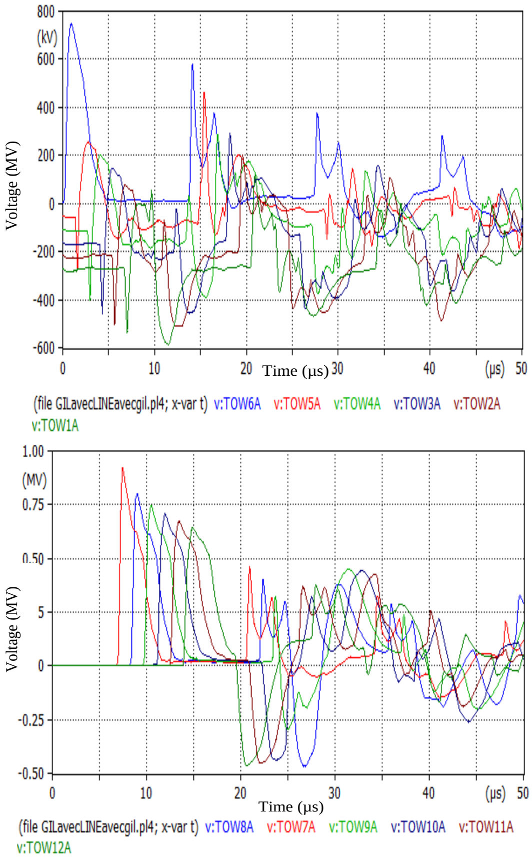


Fig. 8. Induced voltage across the phase conductor "A" (case 3): a) voltage evolution in tower 6, 5, 4, 3, 2, and 1, b) voltage evolution in tower 7, 8, 9, 10, 11, and 12

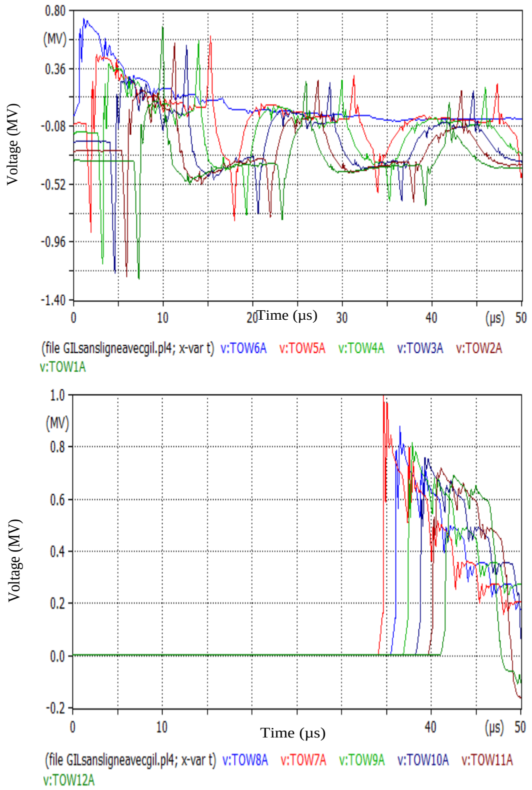
Case 4: Hybrid OHL with surge arrester line, with surge GIL surge arrester.



a)
b)

Fig. 9. Induced voltage across the phase conductor "A" (case 4): a) voltage evolution in tower 6, 5, 4, 3, 2, and 1, b) voltage evolution in tower 7, 8, 9, 10, 11, and 12

Case 5: Hybrid OHL without surge arrester line, with GIL surge arrester.



a)
b)

Fig. 10. Induced voltage across the phase conductor "A" (case 5): a) voltage evolution in tower 6, 5, 4, 3, 2, and 1, b) voltage evolution in tower 7, 8, 9, 10, 11, and 12

5. Discussion

As illustrated in figures (6, 7, 8, 9, 10), the induced voltage across the phase conductor is plotted on a time range from 0 to 50 µs. by changing the configuration and combination of protection systems with and without arresters, the induced voltage patterns change in waveform and magnitude.

We have chosen to present separately the voltages before and after the GIL section, and this in the presence and absence of the overhead transmission line arresters and GIL. the maximum value of the induced voltage is around 2.6 MV, it is reached in the first study case (simple OHL with surge arrester installed) with an almost sinusoidal waveform as shown in figure 6. While it is around 730 kV in case No 4 (OHL and GIL with surge arresters installed) (Fig. 9).

The results obtained in the 3rd case (OHL and GIL without arresters) are visibly disturbed and distorted due to the propagation of the lightning wave on the line without any discharge by arresters (Fig. 8).

The analysis of the results obtained in the cases 4 and 5 shows that the installation of the surge arrester in the gas insulated line (GIL) presented on the figures 9 and 10 has strongly influenced the magnitude and the waveform of the voltages induced on the left and on the right of the GIL, which is in good agreement with the results obtained by the authors of the reference [12].

6. Conclusion

In this paper, the effect of lightning strike on hybrid overhead transmission line is studied.

The use of arresters in Gas Insulated Lines (GIL) is important for several reasons: Overvoltage protection: Arresters protect the GIL from overvoltage surges that can occur due to lightning strikes or switching operations. These surges can damage the insulation of the GIL, leading to costly repairs and downtime. Arresters divert the surge current away from the GIL, preventing damage to the insulation.

Safety: Arresters protect personnel and equipment from the effects of high voltage surges that can occur in the GIL. Without arresters, a surge could cause an electrical fault or explosion, posing a danger to personnel and equipment.

Reliability: Arresters improve the reliability of the GIL system by preventing damage to the insulation and reducing downtime. By protecting against overvoltage surges, arresters help to ensure that the GIL operates as intended, with fewer interruptions or faults.

Cost-effectiveness: The use of arresters in GIL can be a cost-effective solution to protect against overvoltage surges. Without arresters, the cost of repairing or replacing damaged GIL insulation can be high. Additionally, arresters are relatively low cost compared to the potential costs of downtime, equipment damage, or personal injury.

Overall, the use of arresters in GIL is an important part of protecting the GIL system and ensuring its safe and reliable operation.

Neuro-Fuzzy Inference System (ANFIS) controller for Maximum Power Point The MPPT controller plays a crucial role in extracting the maximum available power from renewable energy sources, such as solar panels or wind turbines, in a microgrid system. GSA is used to optimize the parameters of the MPPT controller. The GSA algorithm can explore the parameter space of the controller, such as the gains, setpoints, or control rules, to find the optimal values that maximize the power extraction from the renewable energy sources. GSA's ability to balance exploration and exploitation can be leveraged to fine-tune the controller's parameters and improve its performance.

The ANFIS controller can be employed as the MPPT controller in the microgrid system. ANFIS combines the advantages of fuzzy logic and neural networks to create an intelligent control system capable of capturing and utilizing expert knowledge in the form of fuzzy rules. ANFIS can model the nonlinear characteristics and dynamics of the renewable energy sources and adjust its parameters based on the feedback signals to track the maximum power point.

The efficiency, stability and reliability of a photovoltaic energy are considered major factors for establishing this energy resource on the market. In this research, common maximum power point tracking techniques, using Gravitational Search Algorithm and ANFIS Controller. Adaptive neural fuzzy inference system and artificial neural network have been proposed for a grid-connected PV system to maximise the output power of a PV array. The aim has also been improving the stability and reliability of a PV power conversion, especially in the context of a rapid change in atmospheric conditions.

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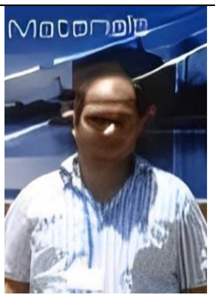

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