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Effects of huge amount of solar energy penetration on grid: A review

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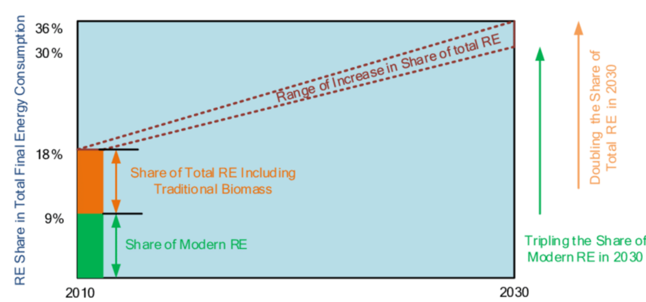
Abstract: The development of renewable energy (RE) technologies is accelerating because of their minimal operational costs, declining investment, and lack of pollutants. As a result, a greater percentage of the generation capacity of the regional grid will be made up of renewable energy. Due to its intermittent and stochastic nature, the incorporation of a significant volume of renewable energy into a regional grid also brings up a number of reliability issues. There is a long-term concern regarding how to comprehensively and effectively examine the impact of the rise in the renewable energy on system reliability. In this article, we offer a novel index system that is simple to calculate and aims to accurately and efficiently assess the influence of fluctuation in renewable energy on reliability. Although the environmental impact of high-level RES penetration is lessened in comparison to traditional fossil fuel-based electricity generation, control difficulties become more difficult because the absence of typical synchronous generators greatly diminishes the system's inertia. The integration of Renewable Energy causes certain additional technical problems like high uncertainties, stability. Because sunlight is intermittent, renewable energy source like solar is quite uncertain. The impacts of increasing solar power plant penetration on the transient stability of power grids were examined in this study using an examination of various photovoltaic power plant penetration levels. The problems faced by integrating high-level RESs into the current grid is outlined in this research. Each challenge's corresponding solutions are shown and analyzed.

Index terms: Intermittent and stochastic nature, Renewable energy sources, control techniques and optimization method, system reliability, uncertainty.

Introduction:

Currently, a lot of environmental issues are brought on by the emissions of dangerous gases carbon dioxide and nitrogen oxide from fossil fuel-based generating stations. Acid rain and climate change are both results of this environmental damage.[1] Economically speaking, when to compared the conventional synchronous based machine power generators, renewable energy (RE) generation systems are seen as being more affordable and cleaner [1]. As a result, some of the organizations are improving them RE generation in order to replace their fossil fuel-based power generation [2]. By 2030, it is predicted that 36% of the world's energy needs will be satisfied by RESs.



A timeline for the production of renewable energy by 2030.[2]

Due to its reduced cost of production and capacity to track its highest power point throughout a wide range of variations in sunlight, solar energy is the most promising. Because of the stochastic nature of solar energy, high-level integration of RE into the utility grid may lead to problems such as stable operation of the system. This is brought on by the continuous fluctuations in sunlight irradiance.[2] By modelling the intermittent and unpredictable nature of the renewable energy sources, we can decrease the effects on the operation of the system. In order to model the uncertainties in the renewable energies various methods were offered in the process of reduction of risk on the system's reliability and the operation of the stable. To maintain steady operation during transients and fluctuations in the AC system parameters, careful regulation of the power electronic (PE) converters linked to the RESs is crucial. Renewable energy sources must remain connected during system faults following grid code requirements. Improvements to the renewable energy conversion system's fault ride through (FRT) capability are therefore crucial. To increase the FRT capabilities of grid-connected solar energy systems, a number of techniques have been proposed in the literature.[3] Systems for converting renewable energy use expensive power electronic converters to condition the power. From an economic and stability standpoint, protecting these converters is crucial. However, when the integration of renewable energy sources is expanded, the power level of short-circuits rise. As a result of supply-demand imbalances, reserve generation reductions, and other issues, uncertainty in the output of renewable energy contributes to frequency instability in the system. Additionally, the extremely low inertia that is a problem for large-scale RESs integrated systems further reduces the stability of the system's frequency [3]. By simulating the operation of a primary mover to artificially increase inertia in the control loop and so stabilize the system frequency, the idea of virtual synchronous generator has been developed. There will be decrease in the reliability of the system when there is high level integration of the renewable energy sources into utility grids. If the power system is not flexible enough, the quantity of renewable energy integration must be limited. The dispatchable generators, for instance, can ramp up quickly to fulfil the load demand in the event of uncertain renewable energy sources.[3] Fast ramping, however, raises maintenance costs, which force plant closures and lower system reliability. Due to the integration of high level of renewable energy into the grid, it requires a quicker frequency control after disruptions by the systems reduced frequency. If the system is slow in reacting under these conditions, there will be problems such as load-shedding and generator damage appear, which lower system reliability. Low voltage ride through was violated due to a substantial variance in PV irradiation. Due to their unique qualities that set them apart from traditional generation resources, high PV penetration levels can considerably alter the system's steady state and transient stability. Thus, a number of solutions, including fault current limiters, energy storage devices are proposed in this study to limit the fault current within acceptable bounds. This study offers a comprehensive overview of the various problems and chances in highly renewable integrated systems in light of the aforementioned issues and their significance. The problems are explained thoroughly in this journal article and include overall inertia reduction, low faulty ride through capacity, high uncertainties, frequency and voltage variability. For every difficulty, additional strategies are also discussed.

ISSUES WITH LOW INERTIA AND FREQUENCY:

Solar photovoltaic (PV) integration lowers the system's overall inertia since it eliminates the need for synchronous generators that aren't renewable energy sources (RESs).[4] Furthermore, as the solar PV plants does not provide any inertia to the power grid, the frequency response is further diminished. Due to this, replacing the conventional synchronous generator with RESs at a high level reduces system inertia and it raises the rate of change of frequency (ROCOF), which triggers the load-shedding controller even at a modest load-generation mismatch.Frequency variation is a result of reduced reserve power brought about by the replacement of reserve generating units.[5] Therefore, it is crucial to develop new RES controllers that behave like synchronous machines in order to improve the system's frequency responsiveness. The various control methods for solar PV systems to enhance frequency response and ensure stable operation are described in the following subsections.

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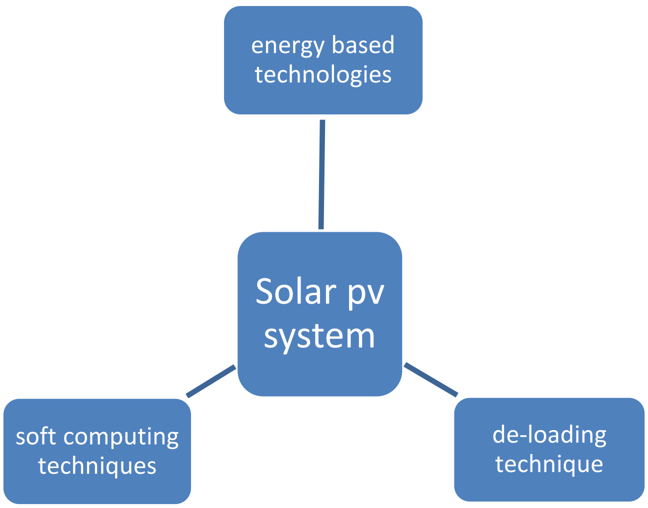
Solar based system:



A photovoltaic solar (PV) system which is connected to the grid can contribute in frequency control during positive frequency fluctuation, which is a spike in system frequency brought on by higher generation than load. Even yet, because it functions at peak power with no buffer margin, it is incapable of partake in frequency control in the event of a negative frequencies excursion. In order to participate in the frequency regulation in the negative frequency excursion in the PV system a reserve must be kept by de-loading or using other techniques.

1)Energy based technologies:

By minimizing the active power variation, energy storage technologies can be used to lessen the negative effects of high PV grid penetration. This article provides droop and step response regulators with energy storage to improve the frequency range of two high Photovoltaic systems US power grids. [6]. In this study, step response controllers were found to slightly outperform droop controllers when used with energy-constrained high-power density storage systems. By regulating its input current and using an effective DC-DC converter control, a battery energy storage system is built to keep up grid periodicity [6]. Furthermore, the controller that is being proposed can enhance the system's ability to ride through faults in the event of various transients.

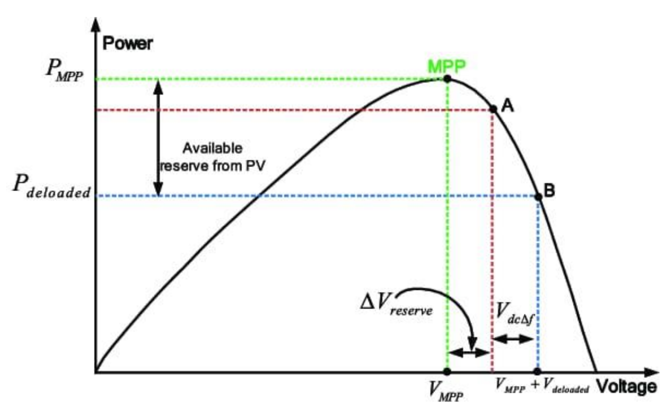
Soft computing techniques:

High-level frequency deviation of the power system is caused by the system's output power fluctuation, which changes with the weather, season, and location. To improve the frequency response, soft commuting techniques were used in the PV system to prevent power fluctuation.[7] Fuzzy logic controllers are used to create output power commands based on frequency variation and average PV system insolation. In that it allows the PV system to be operated near to its maximum power output, the method outperforms the de-loading technique. Similar to the referenced method, another soft computing approach is offered.[7] The output power directives are generated utilizing a fuzzy logic controller and particle swarm optimization to improve the frequency responsiveness of PV systems.

3) De-loading procedures:

Through a de-loading strategy that entails operating the PV system past the MPP, as shown in Figure, the photovoltaic system can maintain system frequency and supply reserve. The point MPP with a voltage of corresponds to the maximum power. V_{MPP} . As demonstrated, the PV system operates at MPP instead. functions with a total reserve of P_{max} -$P_{deloaded}$ at point B. The Figure illustrates the de-loading technique that is explained and shown in [8]. As shown, the following calculation depends on both V_{MPP} and the system's reported frequency deviation ∆F to determine the PV output power.

$$V_{MPP} + V_{deloaded} - V_{dc^{\Delta}f} = V_{dcref}$$



De-loading power-voltage curve for a PV system [8]

ISSUES RELATING TO FAULT RIDE THROUGH (FRT) CAPABILITY:

Rapid PV disconnections in the event of disturbances have a negative impact on the system's stability. The PV plants must therefore be linked to the grid during faults for a predetermined amount of time in order to have FRT capabilities. The current grid code, which varies from nation to nation based on a variety of factors, as shown in Figure. [9] Since the gf is in charge of maintaining the system's low voltage, it is crucial that the renewable sources continue to operate in order to preserve the pf and increase system dependability in emergency situations.

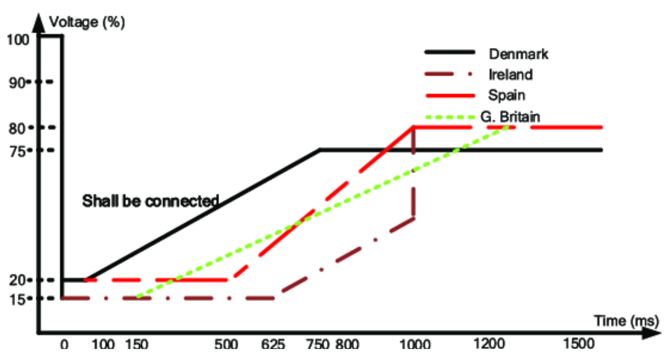


FIG: Grid codes for various nations.[9]

This is achieved through the employment of a number of improved control mechanisms and the placement and control of auxiliary devices powered by renewable sources of energy. Issues with FRT capability for PV systems are covered in the literature. Each of these systems is presented using a different technique, which is grouped in Figure. The main improvement to the PV system's FRT capacity is the addition of auxiliary devices. The literature presents enhanced control tactics and soft computing methods.[9] A model predictive control method with quick and reliable control characteristics is proposed to improve FRT of PV systems.

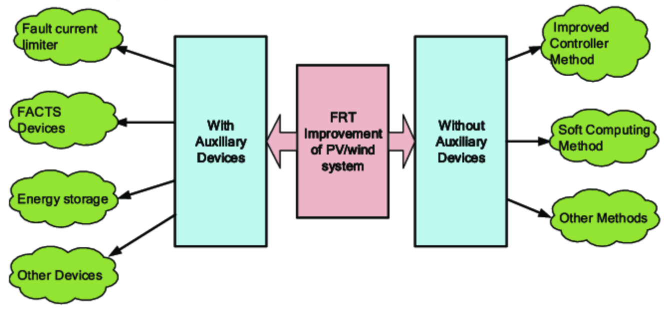


FIG: FRT improvement techniques [9]

UNCERTAINITY CHALLENGES:

Uncertainty in power systems refers to imprecise parameters that cannot be predicted with absolute accuracy and that interfere with efficient operation. Due to its erratic character, renewable energy sources are now regarded as the primary cause of uncertainty in the power system. The main issue is how the grid's operators manage the unpredictability brought on by these sporadic sources of renewable energy as they have been completely incorporated. Most optimization methods, soft computing, advanced control algorithms, and energy storage devices are kept to reduce the consequences of uncertainty. [10] To entirely or partially decrease the uncertainties in the incorporate the RESs, a variety of strategies are applied.

Modern control techniques:

To deal with the uncertainties brought on by the fluctuation in solar irradiation, a number of control mechanisms are also provided in the literature. For DFIG and PMSG production systems, coordinated control solutions are suggested for power output flattening.[11]. The majority of control strategies don't deal with multiple disruptions or unidentified parameters. However, the model predictive control method has the capability to account for both of these. MPC-based control techniques for uncertainty mitigation solar energy systems are described in order to take use of these benefits [11]. Use of the partial feedback linearization method ensures robustness in the face of a variety of solar system uncertainties.

Soft computing approaches:

The network performance in the reliability is negatively impacted by the grid's huge unpredictable renewable energy integration. In order to lessen the burden of uncertainty caused by stochastic renewable energy sources, soft computing techniques are widely used in the power system. The uncertainties in the integration of renewable energy are controlled with soft computing techniques, despite the difficulties they encounter in achieving global optimality. For the solar systems, a hybrid technique based on the genetic algorithm-particle swarm optimization has been reported.[12] When solving an optimization issue using a modified PSO, the load uncertainty and demand fluctuations at random are taken into account. The optimization problem with varied operational limits can be successfully solved using differential evolution (DE), which would be illustrated for the renewable system inside which production uncertainty are added to load changes. To reduce the prediction of renewable energy, artificial neural networks (ANN) were educated with uncertain inputs like solar irradiance.[12] The modelling of reliability, and battery management were done and are developed using an improved weighted PSO method to further reduce the impact of uncertainty.

Energy storages:

A multitude of unexpected system responses are brought on by the uncertainty that emerges from incomplete information during the integration of RESs. As was already said, a variety of optimization/soft computing approaches allow for the creation of RES representations that are resistant to uncertainties; nonetheless, the creation of such models is required by the existence of considerable uncertainties. However, the RES model needed to be developed methodically while taking into account its high-level, intrinsically dynamic characteristics. The best candidates to be used to solve this problem are various storage devices incorporated into the system model. Additional research on a wide range of real-time battery operation strategies may represent a new area of study, and it may also be possible to examine in greater detail how battery lifetime deterioration affects RES uncertainty.[13] A hybrid energy storage system made up of a battery and a supercapacitor is taken into consideration when developing the source and load uncertainties management method. The effectiveness of this hybrid system is also compared to other potential hybrid systems, such as flywheel batteries. According to the current talks, energy storage systems (ESS) play a significant role in reducing and managing uncertainties; nonetheless, it is crucial to determine the ESS's size in relation to the process of reducing uncertainties [13]. In light of the stochastic character of uncertainties, a theoretical ESS sizing approach is put out and its mean absolute error is examined (MAE). In order to reduce uncertainties in the integration of RESs, other methodologies, including probabilistic, optimization-based, and frequency-domain evaluation of the magnitude of ESS, are also used.

Effects on the stability of the power system:

Distributed resources such as PV that take the role of traditional generators are typically situated lower in the voltage spectrum and closer to the loads. As a result, a portion of the generation is moved to places closer to the loads based on the PV penetration level, which might change the quantity of reactive power supplied to the loads. This modification is mostly caused by the restrictions imposed by the line and transmission system component ratings (including transformers). It’s crucial to preserve steady state voltage stability among system buses in a big, interconnected system. Maintaining their values within the range permitted by the operators typically +5% or -5%. High PV uptake leads to the replacement of large-scale. Using distributed PV systems with generating units can reduce the access to reactive power. The reason behind this is that most residential and are believed to comprise the majority of the PV units only active power sources. This could have an impact on the system's dynamic performance, especially when the reactive power supply. In the process of a system disturbance, power is cut to the loads. Consequently, it is anticipated that bus voltages will be more disturbed during the system fluctuations. Additionally, due to the increase in the penetration of the PV level will lead to decreased inertia in the system, which could be the cause of potential issues with rotor angle stability. These issues primarily arise when there are system disturbances, such as bus faults, generating unit losses, and line removals. The next sections go over several types of instability brought on by high PV penetration.

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Stability in a Steady State:

Stability in a steady state refers to a system's capacity to preserve balance while meeting external demand. These restrictions include bus injection limitations and bus levels of operational voltage.

The penetration of PV in high-level can result in changes in the transmission level bus voltage magnitudes. Investigating different PV penetration rates can be useful.

Operators of the system in two ways:

1)Determine the connection between PV penetration rates and the magnitudes of steady state voltage.

2)Identify the high voltage magnitudes brought on by significant PV penetration and take the necessary precautions. Identifying the high voltage-related issues with the buses magnitudes are crucial since they will inform the system planners of the PV system addition's potential negative consequences.

Transient Stability:

The power system's capacity to sustain synchronism amid significant disturbances is known as transient stability. When there is a disturbance that occurred causes a mismatch between the mechanical power input and electrical power output of the generator, generator—turbine inertia typically plays a critical role in giving synchronization capacity to the synchronous generators. The angle variations of the bus voltages can also have an impact on the system's capacity to synchronize power. In order to accommodate a significant power infusion from PV resources, the voltage angles across the ac system must be adjusted. There will be decrease in the synchronizing power ability as result of the difference in the angles between the ac bus voltage. Other factors, such as the type of disturbance and its location in relation to the PV systems and the large-scale generating units, also have an impact on how high PV penetration affects system dynamic behaviour.

COMPLETE REVIEW WITH PV PENETRATION LEVELS:

PV penetration (MW)	2156	4315	6485	8733	10692
PV penetration level (%) (Based on load)	11.2	22.5	34	45	56
PV penetration level (%) (Based on energy)	2.52	5.02	7.51	10.01	12.51

CURRENT CHALLENGES:

Many financial and technological advantages are now acquired from the high-level integration of converter-low-cost, carbon-free energy sources are among the available ones. Low operating and maintenance costs and low emissions. However, lots of technical problems, low frequency of inertia problems unstable conditions, a high fault current as a result of the short circuit. Due to the high level of integration of renewable energy, and irradiance, poor power quality, have increased. It is difficult for researchers to keep such systems operating in a flexible, dependable, and stable manner. The loss of system inertia is the one that hurts the ps the most out of all the problems. because the low system inertia directly affects frequency regulation. If no corrective measures are taken and the power system's frequency begins to decline, multiple producing stations because of the settings for the frequency relay, and the system blackout may result as a result. For instance, if the system is separated from the PV generators because of their limited FRT capabilities mismatch between generation and load makes frequency control challenging.

S.NO.	METHODOLOGY	ADVANTAGES	DISADVANTAGES
1)	Due to the increased solar photovoltaic adoption, a large amount of grid stability difficulties is taking place for the operation of distribution system. Life of the transformer will be reduced due to frequent changes in tap changing adjustments.	More amount of power will be generated when solar energy is applied on the grid. If there is a proper storage facility the solar energy can be utilized properly.	Due to the more amount of solar energy applied at a time the grid may leads to early damage. To avoid the damage production more quality is required with new qualities, so that the grid can resist, which ultimately leads to more cost.
2)	The methodology used here is the quantitative methodology as there are surveys conducted. From the introduction we got to know that solar PV module technology advancing every day so it is difficult to measure actual degradation for solar PV projects.	As the project gets older the expenditure gets smaller.	Due to the degradation, there is chance of development of new ideas to generate power with e-waste etc.,
3)	This study investigates how a large penetration of solar systems affects the voltage in a suburb residential area. Whereas the penetration levels in this investigation might not be regarded as high, the system may be affected differently by the voltage rise.	By lowering transformer short circuit resistance and feeder impedance, the LV network's efficiency would increase, which would lessen voltage rise problems.	There will be a problem such as voltage rise for the rural feeders as these have long span which leads to the increase in the value of the feeder impedance.
4)	This study highlights the occurrences of the outputs power loss caused by the grid voltage rise and describes the grid overvoltage protection function of the connected solar (PV) power generating system.	Only a small percentage of PV systems, compared to the other system, had a considerable amount of production energy loss on a given day.	A small number of systems with low starting voltage set values suffered the majority of the losses.
5)	When huge amount of solar energy penetration on grid then there will be a problem of stability. The following methods gives detail information about various solar PV control strategies to enhance frequency response for reliable performance.	Even though there is a problem of stability it can be resolved by applying strategies to enhance frequency response for reliable performance.	Frequency deviation results from a decrease in reserve power brought on by the retirement of reserve generating units.

S.NO.	METHODOLOGY	ADVANTAGES	DISADVANTAGES
6)	There is a problem of uncertainty with the huge amount of solar energy penetration on the grid to the system operators. We have optimization approaches, soft computing, advanced control algorithms, and energy storage devices for the reduction of the uncertainty problems.	In the power system, soft computing techniques are widely used to reduce the impact of uncertainty caused by unpredictable renewable energy sources.	Due to the grid's extensive incorporation of stochastic renewable energy, network performance is less reliable.
7)	This study seeks to examine and highlight the value of grid-connected solar systems in light of the variability of renewable energy sources. There are times when the production exceeds the net demand at high solar system penetration levels.	For photovoltaic electricity, there is no set maximum permissible penetration level because it relies on network features.	Concentration of dust and cloudy days also reduces the current and power of solar cells.
8)	In light of the intermittent nature of renewable power, this article attempts to investigate and highlight the significance of grid-connected photovoltaic systems. There are times when net production exceeds net demand at high levels of solar system penetration.	For photovoltaic electricity, there is no set maximum permissible penetration level because it relies on network features.	The power and output of solar cells are also decreased by cloudy days and dust concentrations.
9)	The efficient running of the electric grid is seen as the main problem. This case study focuses on Tajikistan's electricity network operation. One of the places where solar energy is most appropriate is Tajikistan. The high degree of energy losses in the Tajik electric network makes it difficult to operate the country's power grid.	Because of its location, natural features, and meteorological circumstances, Tajik is regarded to be one of the most favorable places to use solar energy.	It is discovered that there is an issue with excessive solar production during the weekends, which results in active transferring power from the customer to the grid.

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S.NO.	METHODOLOGY	ADVANTAGES	DISADVANTAGES
10)	Numerous dependability issues are brought on by the grid's integration of a significant proportion of renewable energy. The idea of Capacity Credit, which is the most extensively used and acknowledged index to quantify the reliability coefficient of solar in the power system, was applied in this quantitative study approach. The proportion of renewable energy to a regional grid's supply sufficiency is measured by Capacity credit.	Negligible operating cost, zero pollution and renewable energy technology has a rapid development. Novel Index System is easily implemented.	Renewable energy has non-continuous and stochastic nature which breaks the valance. CC focuses on supply adequacy aspect, which is not sufficient for proper measurement.
11)	In this we used quantitative and descriptive methodology, it is quantitative because there is a lot of analysis in this article on the renewable energy. With the elimination of a sizable number of synchronous machines from the grid, a problem with power system protection will emerge.	Large installations of renewable energy come with additional difficulties, but there are also numerous options that can offer the adaptability required to deal with these difficulties.	Because solar energy's output is erratic and dependent on the local weather, we cannot entirely rely on it.
12)	Analytical technique is the one employed in this paper. At the point of common coupling, the voltage, current, and power of solar PV have been studied. The research is conducted in a MATLAB/Simulink environment utilizing a test system that includes conventional generators, loads, transmission lines, transformers, and a solar PV system that is integrated through converters.	In the foreseeable future, PV technology will fare well since PV module costs are steadily declining and they are becoming more affordable.	Technical difficulties include voltage instability, harmonics, reactive power, poor power factor, load shifting, and stability issues can arise when solar PV systems are integrated with the utility grid.

CONCLUSION:

Despite the benefits, the integration of the renewable energy to the grid still creates a number of significant problems, such as low-level inertia and high levels of uncertainty. The purpose of this essay is to provide a thorough and in-depth analysis of the problems and solutions associated with the integration of high-level renewable energy sources to the grid. There are some difficulties that are pointed out and examined, including poor inertia, high fault current, and high uncertainty. Also, some of the upcoming problems were mentioned. The impacts of high-level energy integration on power system stability. The study of steady state and dynamic behavior of the system is done.

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