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Assessment of Optimal Allocation of Renewable Photovoltaic Sources in Electrical Power System Networks

Shimaa A. Ashry[1], Gamal A. Morsy[2], Ragab A. Amer[2], and Asmaa F. Nasef [2, *]

[1].Department of Engineering., EPC., Madkour Group., New Cairo., Egypt
[2] Department of Electrical Eng., Shebin Elkom Faculty of Eng., Menoufia University, Egypt.
*(*Corresponding author: nasefasmaa@yahoo.com)*

ABSTRACT

This paper aims to determine the optimum locations for renewable energy sources (RES), specifically photovoltaic (PV) power plants, based on two indices: line stability index and voltage stability index. The analysis comprises power flow analysis, short circuit analysis, and power quality analysis. The effectiveness of the method is demonstrated with the IEEE-9 bus network and a real system (new delta substations) consisting of 18 substations, considering various scenarios involving changes in the penetration levels (PLs) of PV power plants and the substitution of centralized units with distributed units. The optimum locations and PLs are selected that minimize the active and reactive power losses, enhance the system's voltage profile, and guarantee adherence to power quality specifications, which include keeping the voltage and current harmonic distortion within predetermined limits. This investigation employs DIgSILENT Power Factory as a software tool that enables all necessary analyses and investigations on the grid. Finally, this article offers a variety of methods for reducing harmonic distortion, which helps to keep voltage and current distortion within acceptable limits. The results are thoroughly analyzed and presented in comparative form.

Keywords: *PV penetration level; Short circuit analysis; Renewable energy sources; Voltage indices; Total harmonic distortion.*

1. Introduction

The escalating global climate change and the increasing demand for electrical power have made it necessary for power system operators to increase electricity generation [1-2]. However, traditional methods of generating electrical energy have resulted in numerous environmental problems, including greenhouse gas emissions and global warming [3]. Generation of electricity from renewable energy sources (RES) has been playing an important role lately with a large integration scale [4], due to many environmental, economic, and technical benefits from them [5-6]. These resources can also be used on a repeated basis to produce useful power energy, Job creation, the ability to complete the world's energy required, and community development [7]. The technical benefits of these sources are possible to be clarified in the following points and their reasons. According to the location and size of the generation power plant, there are two types of generation systems: centralized power plants and distributed power plants, in centralized power plants the location of the generation units is far away from the load center with a nominal rating power from 100 MW to some of GWs. On the other side, the distributed generation units are located near the load center with nominal rating power from some kilowatts to some of the megawatts [8]. The above words concur that the distribution power plant can reduce the electrical power losses through the transmission lines and the cost of transmission lines, also these generation technologies can increase the system stability and reliability [9-10]. Furthermore, the major objectives of distributed generation in electrical system networks are voltage profile improvement, increased voltage stability, and load balancing [11]. So, during recent decades centralized energy sources have been replaced with decentralized ones known as renewable energy distributed generation (REDG). On the other hand, the widespread use of such technologies introduces new challenges to power systems like power fluctuation, voltage fluctuation, reverse power flow, voltage rise, power factor changes, and generating harmonic waves in the fundamental wave [12-13]. Photovoltaic distributed generation (PVDG) is the most common spread of REDG .

The integration type depends on the generation capacity of solar power plants. The first type is the medium-sized solar power plant (MSSP) with nominal generation power from 0.5 MW to 20 MW. The second type is the large-size solar power plant (LSSP) with a nominal power of more than 20 MW [14]. It is a beneficial solution to use this integration in the distribution system because it supports power quality, reduces power losses, reduces peak load, and increases reliability [15]. Meanwhile, the negative impact of PVDG, such as reverse power flow, voltage fluctuations, and system instability, would occur in the case of PVDG with high penetration levels so short circuit analysis, power quality analysis, and power flow analysis are very important to do on the system to avoid these negatives.

Major technical approaches for optimal PVDG allocation are categorized as analytical approach, classical (non-heuristic) approach, meta-heuristic optimization approach, hybrid approach and assorted approaches [16, 17]. The most popular optimization approaches for PVDG allocation are Genetic Algorithm (GA) [18], Particle Swarm Optimization (PSO) [19], Ant Colony Optimization (ACO) [20], Artificial Rabbits Optimization (ARO) [21], Artificial Bee Colony (ABC) [22], and so on.

The connection between the PV power plant and the network occurs via electronic equipment like inverters. Large-scale integration of PV power plants will generate harmonics in the system due to inverters which are required for integration [23-24]. The presence of harmonics in the electrical system will be followed by many negatives such as heating (motors, cables, transformers, neutrals), increased voltage between neutral and earth, failure in capacitor banks, and tripping of circuit breakers and fuses. Several studies have been performed to study the impact of integration PVDG on the electrical power system network, while limited studies investigated the harmonic impact of integration in the electrical network taking the effect of centralized and distributed power generation into consideration. In [25], a study was carried out on a medium voltage grid integrating PV power plants (centralized and decentralized) through a load flow analysis, a short circuit analysis, a power quality analysis, and an economic analysis carried out in both cases. the results show that decentralized PV plants are less profitable than centralized PV plants from an economic point of view, but on the other hand, the grid performance is better with decentralized plants, since the active and reactive power losses are reduced and the voltage profile at the busses is improved. In [26], an overview of harmonics in a PV-integrated grid is given. The conclusions of the results show that the amount of total harmonic distortion (THD) in the grid depends on the percentage of PV penetration, PV location integration, harmonic resonance in the grid, and the output power of the PV inverters, which depends on the solar irradiance conditions. The higher the percentage of PV penetration, the higher the THD of current and voltage due to the multiplication of PV inverters and nonlinear load. When the PV integration location is at the far end of the feeder, the THD of current and voltage are high and low at the beginning of the feeder, which is due to the short-circuit level in the grid. In [27], an analysis of harmonics in the integration of renewable energy sources was carried out under different scenarios depending on the respective penetration level of the distribution network (DN). It was found that the harmonic distortion of the grid increases as the penetration level of RES increases.

This paper aims to identify the optimum locations for the deployment of renewable energy sources (RES) in the form of photovoltaic (PV) power plants utilizing line stability index and voltage stability index. The analysis includes power flow, short circuit, and power quality assessments. These evaluations are conducted on the IEEE-9bus network while considering different scenarios based on the penetration level (PL) of the PV power plant and the replacement of the centralized concept with a distributed concept. The objective is to determine the most optimal positions and PLs that lead to minimum active and reactive power losses, enhance the voltage profile, and ensure compliance with power quality requirements, such as maintaining the harmonic distortion of voltage and current within the standard limits. This research is carried out utilizing DIgSILENT Power Factory, which is a computer tool for all the necessary analyses and investigations on the grid. Finally, in this article, several methods for reducing harmonics are presented, which help to keep the distortion of current and voltage within the standard limits.

2. A Methodology for Assessing Grid Impact with DIgSILENT Power Factory

DIgSILENT Power Factory, a software program for digital simulation and electrical network calculation, was established in 1985 by a consulting and software company [28-29]. This electrical power system analysis software features a graphical environment that allows for the creation of single-line diagrams of electrical power system network equipment [30]. With an extensive library for grid components, the software can model and analyze various systems, including generation, transmission, distribution, and industry. The designers are provided with advanced integrated and interactive software that contains a multitude of required functions and types of equipment that are editable for planning, designing, monitoring, testing, reporting, operation optimization, and developing the system according to international standards. Additionally, users are provided with all required training, tutorials, and guides to enhance their proficiency in using the program. The software also offers rich interfacing and system integration options, such as GIS, SCADA, EMS, and EPS [28-29].

DIgSILENT Power factory has been used extensively to conduct various studies, including those related to the impact of integrating renewable energy sources as a distributed generation with the network. The study examined two non-PSA methodologies and one alternative PSA technique that uses load flow sensitivities (LFS) [31]. Furthermore, this paper endeavors to investigate the influence of photovoltaic sources as distributed generation on harmonic voltage and current distortion with three distinct scenarios by utilizing DIgSILENT Power factory as well as conducting three primary evaluations, namely load flow assessment, short circuit assessment, and power quality assessment [32].

3. Simulation and Results

3.1 Systems under study

The effectiveness of the method is demonstrated with two electrical systems as the IEEE-9 bus as a sub transmission network and a New Delta substation as a real system related to Egyptian electricity company.

3.1.1 The IEEE 9-bus system

The system under investigation is the electrical power network of the IEEE-9 bus. This network comprises 9 buses, 3 generators that generate a total power of 567.5 MVA with a power factor of 0.85, 3 loads that have a real demand power of 315 MW&115MVAR, 6 lines, and 3 transformers. The slack bus is Generator 1 on Bus 1, while the other two generators are structured to regulate the injection of active power and voltage magnitudes at the connected buses. The per-unit values of the network parameters are based on 100 MVA and 230 kV. The loads are independent of voltage but maintain a constantly active and reactive power. The system's generators, lines, transformers, and load parameters are sourced from [33]. The single-line diagram of the scrutinized power system is illustrated in Fig. 1.

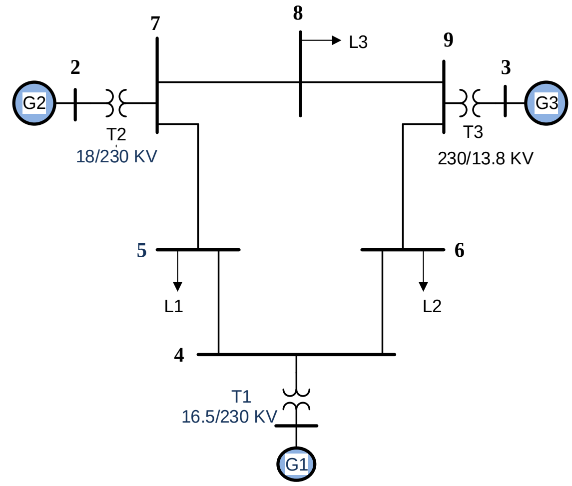

Figure 1- Single line diagram of IEEE-9 bus power system.

3.1.2 The Real System

The system under investigation is the electrical power network of New Delta substations and connecting them with the national grid. This network comprises of 18 substations containing 33 buses with voltage rating 500, 220 & 66 kV, with a power factor of 0.92, 13 actual estimated loads that have a real demand power of 1358 MVA and 27 additional loads that have a real demand power of 3515 MVA to make all transformers in substations loading within range from 75 to 87%, 50 lines, and 33 transformers. The loads are independent of voltage but maintain a constantly active and reactive power. The single-line diagram of the scrutinized power system is illustrated in Fig. 2.

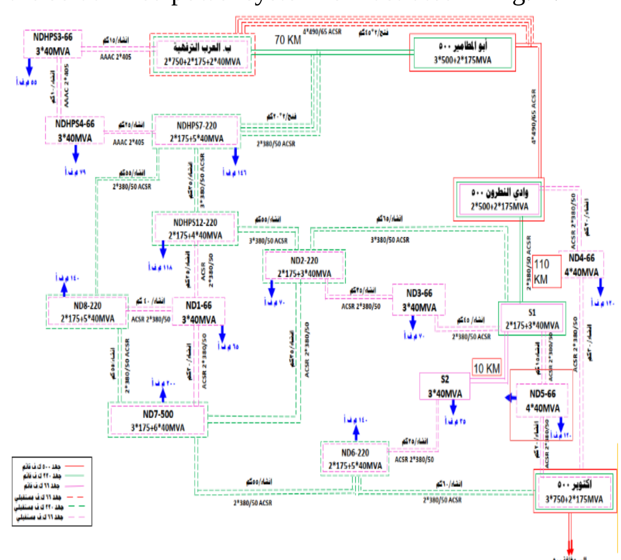

Figure 2- electrical power network of New Delta substations and connecting them with the national grid.

3.2 Solution Methodology

By using the DIgSILENT power factory 15.1 as a leading power system analysis software application for use in analyzing generation, transmission, and distribution for modeling and implementing the IEEE-9 bus system as a sub transmission network and a New Delta substation as a real system for our study. An effective technique is used to determine the optimum location and penetration level for PV power plant integration.

Two indices are introduced to ranking the system buses to select the optimum location for RES to minimize active power losses and improve voltage profile, namely [34]:

A. Fast Voltage Stability Index (FVSI).

B. Line Stability Index (LQP).

$$FVSI = \frac{4\,Z^2 Q_j}{V_i^2 X} \quad (1)$$

$$LQP = 4\left(\frac{X}{V_i^2}\right) * \left(\frac{X}{V_i^2} * P_i^2 + Q_j\right) \quad (2)$$

Where:

Z refers to line impedance, X refers to the line reactance, Q_j refers to the reactive at the receiving end, V_i refers to the voltage sending end value and P_i refers to the active power at the sending receiving end. Fig.3 shows a simple typical one-line diagram for two bus systems.

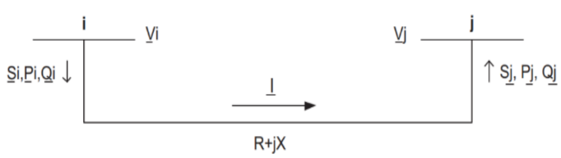

Figure 3- Typical one-line diagram of two bus systems.

FVSI and LQP indices are sorted in ascending order and higher values determine weak buses [34].

The ranking process in the first system, IEEE 9 bus will occur for load buses only (Bus 5, Bus 6, and Bus 8) as listed in Table 1.

Table 1- Prediction of voltage collapse for IEEE 9-bus in power system using voltage stability indices

Results	FVSI	LQP
Average Value for Bus 5	0.099	0.134
Average Value for Bus 6	0.075	0.092
Average Value for Bus 8	0.061	0.067

Table 1 illustrates the optimum location for PV integration is Bus 5, then Bus 6, and then Bus 8. Also, a lot of iterations are made in the DIgSILENT power factory to check the impact of this ranking on active power losses and voltage profile waveform as will be displayed in the following results.

The ranking for the real system is estimated with load buses as (Buses 14, 16, 18, 22, 24, 26, 27, 28, 29, 30, 31, 32, and 33), as listed in Table 2.

Table 2- Prediction of voltage collapse for real system in power system using voltage stability indices

Bus Number	FVSI	LQP	Bus Number
BUS-3-1	0.20	0.20	BUS-3-1
BUS-1-6	0.18	0.18	BUS-1-6
BUS-1-8	0.12	0.12	BUS-1-8
BUS-1-4	0.10	0.10	BUS-1-4
BUS-3-2	0.10	0.09	BUS-3-2
BUS-2-9	0.09	0.09	BUS-2-9
BUS-3-0	0.07	0.06	BUS-2-4
BUS-2-4	0.06	0.06	BUS-3-0
BUS-2-8	0.05	0.05	BUS-2-8
BUS-2-7	0.05	0.04	BUS-2-7
BUS-3-3	0.03	0.03	BUS-3-3
BUS-2-2	0.02	0.02	BUS-2-2
BUS-2-6	0.01	0.01	BUS-2-6

Table 2 illustrates the optimum location for PV integration is Bus 31, then Bus 16, then Bus 18, and then Bus 14 as shown the above table. Also, a lot of iterations are made in the DIgSILENT power factory to check the impact of this ranking on active power losses and voltage profile waveform as will be displayed in the following results.

3.3 Simulation Results

3.3.1 9-Bus Electrical Power System Network

The load flow analysis, short circuit current calculation, and harmonic analysis studies have been done to focus on the impact of PV integration on system performance. Various studies are performed to obtain the optimum penetration levels (PL) of PV sources and locations. The effect of photovoltaic sources on

- Active power losses.
- System voltage profile.
- Harmonics in electric power systems.

a. Impact of PV integration to the 9-bus electrical power system network on active power losses.

There are three cases each one depends on the location of integrating the PV power plant into the electrical power system network with different PL where PL is calculated from Equ. (3).

$$PL = \frac{PV\ Power\ Generation * 100}{Required\ Load\ Power} \quad (3)$$

To indicate the importance of using the FVSI and LQP as a measure for the optimal location of PV sources, the following cases have been considered for 9-Bus system.

Case 1: PV sources are integrated into the recommended bus according to the used indices (at bus 5).

Case 2: PV sources are integrated into a bus near that recommended (at bus 6).

Case 3: PV sources are integrated into a bus remote from that recommended (at bus 8).

Base Case:

In the base case, there are no PV sources on the electric power system network. The total active power losses in the system are equal to 4.64 MW.

Case 1:

In this case, the PV Source is located at bus 5 in the system with different PLs. PL varies from zero to 22%. Taking into consideration that all values of PL are less than 22% in this case due to the slack generator absorbing electrical power from the network when the PL increases above 22% the maximum PL for the studies to this system will be 22%. Fig. 3 shows the variations in the active power losses versus PV penetration levels when the PV was integrated on bus 5, bus 6, and bus 8. As shown in Fig. 3, When the PV penetrated at bus 5 (recommended bus), system losses were decreased with an increase in penetration level until an optimal value of the penetration level and then increased again. This optimal penetration level for the system is about 15% corresponding to losses of 4.43 MW.

Case 2:

In this case, the PV sources are located on bus-6 in the electrical power system network with different PLs. The results like those obtained in case 1 are obtained at low penetration levels. However, an increase in losses w.r.t case 2 is observed with the increase in the penetration level. The optimal penetration level for the system is about 11% corresponding to losses of 4.48 MW, and all other PLs will increase the active power losses as shown in Fig. 3.

Case 3:

In this case, the PV sources are located on bus-8 in the electrical power system network with different PLs. As shown in Fig. 3, when the penetration occurs for the system at bus 8, the losses increase with an increase in penetration level even at lower values of penetration levels, the system losses are more than in any other case as shown in Fig. 3.

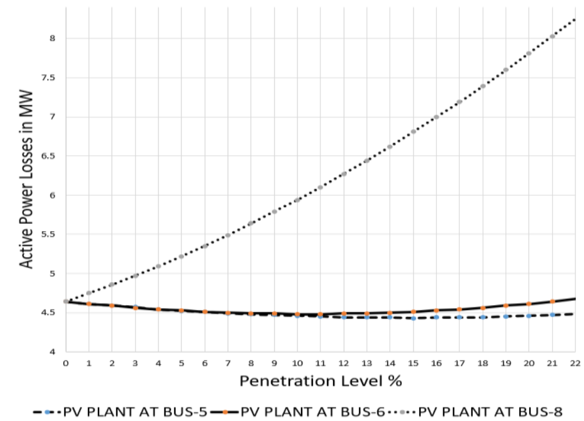

Figure 3- Active Power Losses in MW when PV located on bus 5, 6, or 8 with different penetration levels (PL).

b. Impact of PV power plant integration to the electrical power system network on voltage waveform profile.

There are three cases as shown in Fig. 4. Each one depends on the location of integrating the PV power plant to the network with PL 15%. All results from load flow analysis by DIgSILENT power factory. Fig. 4 shows the voltage at each bus in the electrical network in per unit values in different operations scenarios.

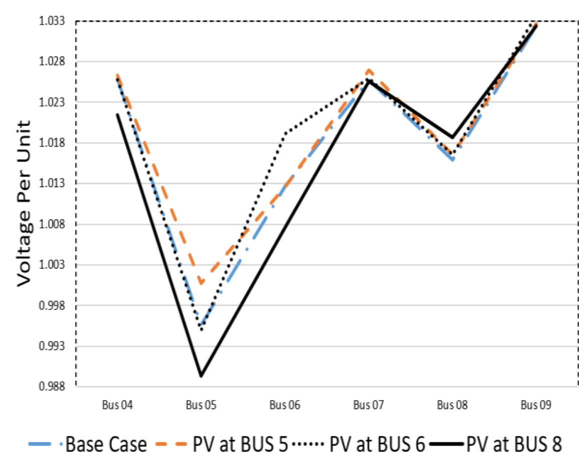

Figure 4- Voltage Profile in PU when PV located on Bus 5, 6, or 8 with Penetration Level (PL) = 15%.

Base Case:

In this case, there is no integration between the photovoltaic (PV) power plant and the electric power system network. The voltage per unit value at each bus is depicted in Figure 4. These findings have been derived from the load flow analysis conducted within the power factory. It is noteworthy that all values comply with the grid code limits as stipulated by reference [35].

Case 1:

In this case, the photovoltaic power plant is situated on bus 5 within the electrical grid, with a PL of 15%. The voltage per unit value can be observed in Fig. 4. As depicted in the voltage waveform profile, this scenario represents the ideal case for waveform, when compared to other scenarios.

Case 2:

The present scenario entails the placement of the Photovoltaic (PV) power plant on bus-6 in the electrical network that possesses a PL of 15%. The voltage per unit value can be observed in Fig. 4, and it is crucial to note that all values comply with the grid code limits as per reference [35].

Case 3:

In this instance, it is noted that the photovoltaic (PV) power plant is situated on bus-8 within the electrical network and possesses a PL of 15%. The voltage per unit value can be observed in Figure 4. Moreover, it is important to highlight that all values conform to the established grid code limits, as referenced in the literature [35].

By analyzing the effect of incorporating a PV power plant into the electrical grid concerning active power losses and voltage profiles under various conditions, it has been demonstrated that the most favorable placement is at bus-5 with a PL of 15%.

c. Impact of integration of PV power plant to the electrical power system network on total harmonic distortion for current and voltage waveforms.

The level of total harmonic distortion (THD) depends on the penetration level and location of the PV power plant on the electrical power system network. Analysis of total harmonic distortion by studying the voltage harmonic distortion under these conditions, PL 15% By locating PV at bus-5 in the first case, bus-6 in the second case, and bus-8 in the third case to show the impact of integrating PV power plant to the electrical network as shown in Fig.5 soiled black line shown the limits of voltage total harmonic distortion according to IEEE-519-2014 standard [36]. Limits depend on the voltage level of the bus.

First case:

In this case PV power plant with PL 15% and located on bus 5. As shown in Fig. 5 voltage total harmonic distortion at busses 4, 5, 6, 7, 8, and 9 are above standard limits.

Second case:

In this case PV power plant with PL 15% and located on bus 6. As shown in Fig. 5 voltage total harmonic distortion at busses 4, 5, 6, 7, and 9 are above standard limits.

Third case:

In this case PV power plant with PL 15% and located on bus 8. As shown in Fig. 5 voltage total harmonic distortion at busses 5, 7, and 8 are above standard limits.

Taking that into consideration photovoltaic power generation (PV) is represented as a static generator with a nominal apparent power of 315 MW. This integration contains internal static converters (Inverters) to convert the output DC from photovoltaic cells to AC voltage. Inverters' impact on the grid will be represented as a harmonic current source referred to as fundamental current using a 12-pulse bridge rectifier. The percentage between I_h to I_f shown in Table 2 for harmonic orders according to the ABB user manual [37].

Table 2- Harmonics on the AC side of a 12-pulse bridge (line current)

harmonic order	5	7	11	13	17	19	23	25
I_h / I_f	0%	0%	9%	7%	0%	0%	4%	4%

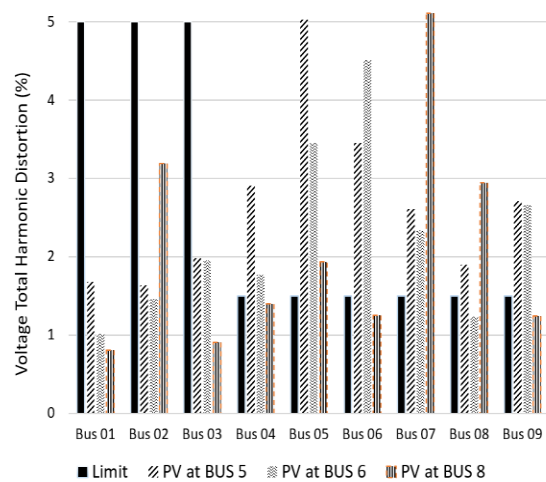

Figure 5- Voltage total harmonic distortion when PV located on bus 5, 6, or 8 with Penetration Level (PL) 15%.

As shown also in Fig. 5, when PV is located near the load center voltage total harmonic distortion will increase at all busses but when it is located far away from the load center total harmonic distortion will decrease in the system and only some busses will be above standard limits.

d. Harmonics Mitigation in Photovoltaic Integrated to Electrical Power System Network

The main aim of this part is to use a management technique to maintain the total harmonic distortion within the standard limits and check results with the limits of current total harmonic distortion to ensure the quality of energy supply in the electrical power system network. To limit the excessive harmonics in the network. The proposed harmonic managements are PV located, changing PL, or using distributed power generation instead of centralized power generation.

a. Changing PV Location in the Electrical Power System Network.

Voltage total harmonic distortion is observed as high When the PV power plant is located near to the load center, and low when located far away from the load center.

b. Changing PL of PV Power Plant.

By increasing the percentage of PV penetration level, the voltage harmonic distortion will increase due to the increase in the number of PV inverters. So, in this case, the PL of the PV power plant will be decreased to 4% to ensure the standard limits [36], as shown in Fig. 6.

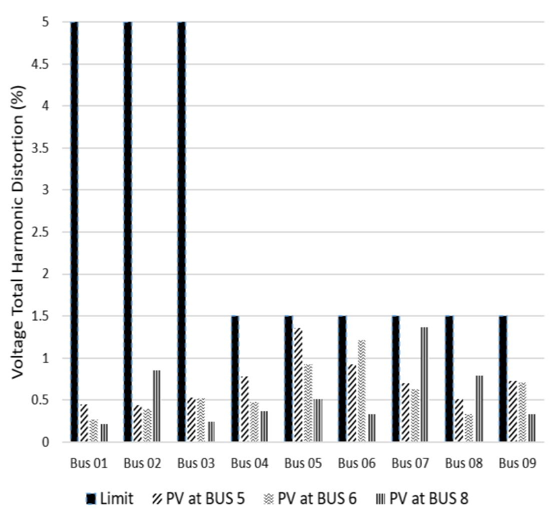

Figure 6- Voltage total harmonic distortion when PV located on bus 5, 6, or 8 with Penetration Level (PL) 4%.

c. Replacing centralized power plants with distributed power plants.

By replacing the centralized power plant with a distributed power plant, the voltage harmonic distortion will decrease on buses and the harmonic distortion for voltage and current are within standard limits. In this case, distributed power plants are used with a total PL of 10%; the PV power plant is located on bus-5 with PL 5% and the PV power plant is located on bus-6 with PL 5%. As shown in Fig. 7. The voltage harmonic distortion through all system buses within the total voltage harmonic standard limits [36].

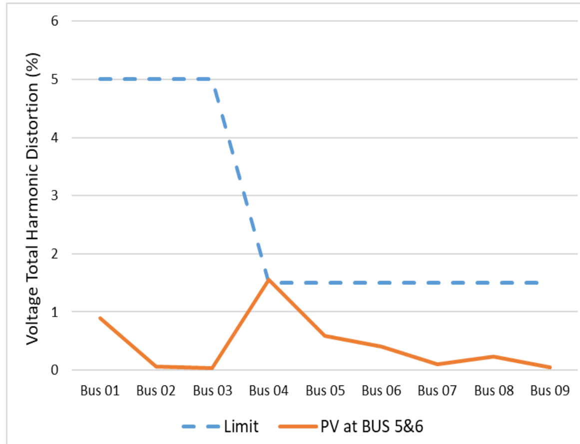

Figure 7- Voltage total harmonic distortion when PV located on Bus 5 and 6 with a total penetration level (PL) of 10%.

e. Final Study Case

In the case study, the impacts of integrating a distributed PV power plant on bus-5 with PL 5% and bus-6 with PL 5% on voltage waveform profile, losses, voltage total harmonic distortion, and current total harmonic distortion were studied. The total active power losses through the system are 4.42MW. As shown previously in Fig. 7. total voltage harmonic distortion at all buses is within the standard limits. As shown in Fig. 8. The voltage waveform profile is within the standard limits and all per unit values are applicable [3].

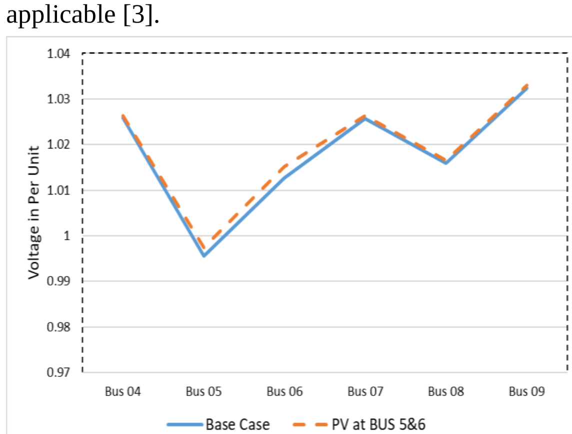

Figure 8- Voltage waveform profile in PU when PV located on buses 5 and 6 with Total Penetration Level (PL) = 10%.

<u>Total Current Harmonic Distortion</u>

To study the impact of integrating PV power plants into the network it is required to load flow analysis, short circuit calculation, and harmonic analysis to have load current at each bus, short circuit current, and total current harmonic distortion. As shown in Table 3. And Fig. 9 the current total harmonic distortion is within standard limits [36].

Table 3- Current Total Harmonic Distortion when PV located on buses 5 and 6 with a total Penetration Level (PL) of 10%.

BUS	Isc (kA)	IL (kA)	Isc/IL (kA)	TDD LIMIT (%)	TDD (%)
Bus 01	57.007	1.6	35.6	8.0	2.11
Bus 02	47.725	5.1	9.4	5.0	0.04
Bus 03	48.362	3.5	13.8	5.0	0.02
Bus 04	3.052	0.1	30.5	8.0	2.11
Bus 05	2.255	0.3	7.5	5.0	0.13
Bus 06	2.146	0.2	10.7	8.0	0.10
Bus 07	3.081	0.4	7.7	5.0	0.04
Bus 08	2.455	0.3	8.2	5.0	0.06
Bus 09	2.771	0.2	13.9	5.0	0.02

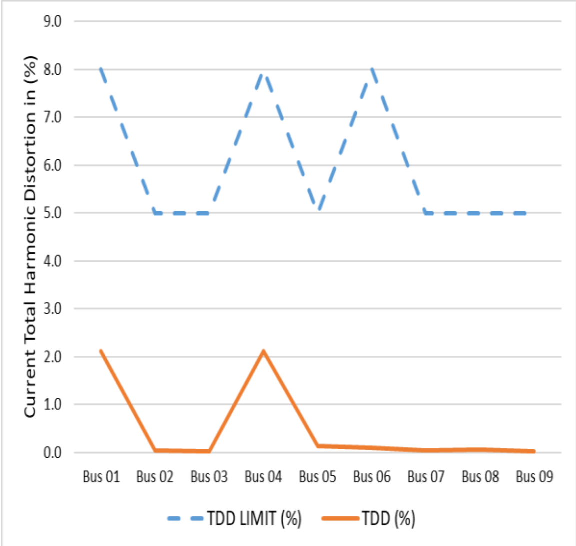

Figure 9- Current Total Harmonic Distortion when PV located on Bus 5 and 6 with total Penetration Level (PL) 10%.

3.3.2 Real Electrical Power System Network

load flow analysis was done on the real system in the event of a photovoltaic power plant located at Bus-31 with a capacity of 500 MVA. The voltage profile is depicted in the plot below.

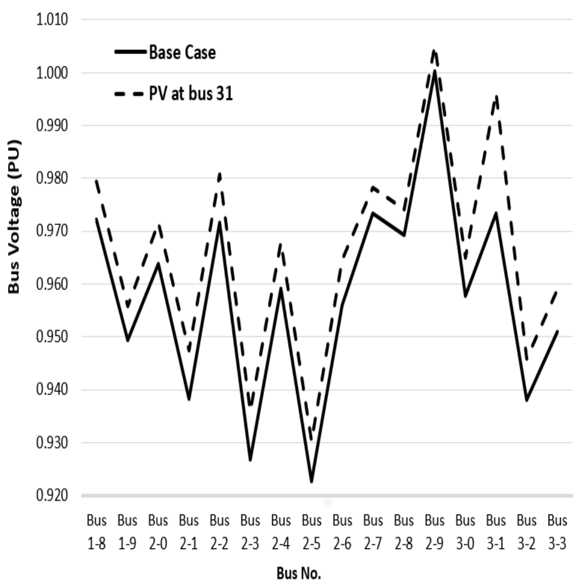

Figure 10- Voltage waveform profile in PU when PV located on bus-31 with Total Penetration Level (PL) = 10.23%.

the voltage profile waveform for the system was enhanced by integrating a photovoltaic (PV) power plant at Bus-31, as depicted in the figure above.

To determine the most suitable degree of penetration for the integration process, various penetration levels are employed to achieve the lowest possible losses. This is done while the active power losses in the network under normal conditions is 63.18 MW without PV power plant. The below table show the power losses through the network with different penetration level.

Table 4- Power Losses when PV is located on Buse-31

Penetration Level (%)	Power of PV Plant (MW)	Ploss (Mw)	Qloss (MVAr)
5	243.65	52.5	929.4
7.5	365.475	50.4	871.0
10	487.3	50.3	833.4
12.5	609.125	52.4	816.8
15	730.95	56.8	822.8
17.5	852.775	63.9	854.3

4. Simulation Results by Optimization Techniques

Two optimization techniques are applied to obtain the optimal location and size of the PV units in the IEEE 9-bus system based on minimizing active transmission losses. Particle Swarm Optimization (PSO) and a new optimization technique as Artificial Rabbits Optimization (ARO) are used to obtain the optimal location and size of one and two PV units. More details on the two optimization techniques are in Refs. [19, 21], respectively. They are applied with the same circumstances: the population is 100; number of iterations is 300; and number of run times is 20. The results as summarizes in Table 5. The results illustrate that both techniques give approximately the same results in the optimization process for one PV unit and two units. The optimal allocation based on minimizing the power losses reduces the total active power losses by about 2.86% using one unit and 5.39% using two units compared with the base case. Also, the convergence characteristic curve ARO algorithm is shown in Fig. 11. This figure illustrates a faster conversion of the objective function that recommends the ARO to solve the optimal PV allocation problem.

Table 5- Summary of optimal PV units' allocation

Cases	Penetration level (%)	PV Location	PVs Size P (MW)	Total losses (MW)
Base	0	No	0	4.64
PSO	One unit (14.16%)	5	44.63	4.5074
	Two units (21.73%)	5	40.35	4.39
		6	28.1	
ARO	One unit (14.16%)	5	44.63	4.5074
	Two units (21.77%)	5	40.72	4.38
		6	27.88	

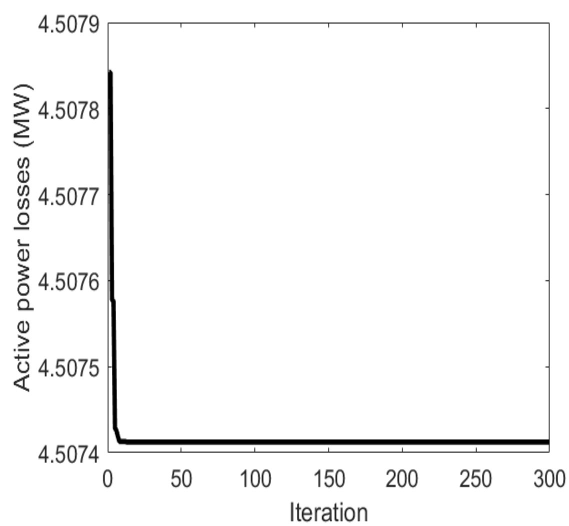

Figure 11- Convergence characteristic of ARO algorithm

5. Conclusions

Based on the results using the fast voltage stability index and line stability index to determine the optimum location of PV power plant in the IEEE- 9 bus and real electrical power system network. It is found that the optimum location is at bus 5 for IEEE-

9 bus also for a real system the integration of PV power plant at Bus-31 improved the systems voltage profile and reduce the active power losses. The results for IEEE-9bus were also checked by a lot of iterations to determine the optimum location and penetration level for integration of the PV units found that for the lowest power losses through the network and optimum voltage profile, it found integration at bus 5 with PL 15% is the optimum selection. However, when studies were done for voltage harmonic distortion all values where above standard limits so harmonic mitigation techniques were used to make all values under standard limits. The first technique is to change the location of the PV power plant, but it will have negative effects on power losses and voltage profiles. The second technique reducing the PL of PV power plants was effective but with small variation values of PL. The third technique is to connect PV units distributed, not concentrated, in one bus. The last technique is the most effective technique the integration occurs on buses 5 and 6 with a total PL on them equal to 10% and this integration with this PL achieved all required limits for power losses, voltage profile, voltage harmonic distortion, and current harmonic distortion according to national and international standards. Verify the validity of the result by using optimization techniques as PSO and ARO techniques.

6. References

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