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Solar PV Placement and Sizing for Line Stability Enhancement and Optimal Operating Cost

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Abstract: ***Nowadays, many countries have started to implement and installed solar photovoltaic (PV). The initial designs of existing power systems were not integrating with any renewable energy (RE) including PV. So, the small scale PV may not have any effect on these power systems. However, integrating large scale PV might raise several power quality issues including power system stability. Power system stability has become major attention where the main focus is on voltage stability.Voltage stability is related on electrical grid capacity to balance the Total Power of Demand (P_D) and Total Power generated by Generator (Pgtt). Instability of the voltage can cause inability of the power system to meet the demand of reactive power. The lack of reactive power will cause instability in the power system.This paper present optimal placement and sizing of PV for stability enhancement and operating cost minimization. In this research, reactive power has gradually increased and Fast Voltage Stability Index (FVSI) is applied to analyze voltage stability. PV is applied to stabilize voltage stability of the power system. Economic Load Dispatch (ELD) is conducted to determine the optimal cost and loss. DEIANT is conducted to optimize the total cost and the total loss after solar PV implementation. Simulation result indicates the effectiveness of the proposed technique for stability enhancement and operating cost minimization.***

Keywords: ***Renewable Energy; Solar Photovoltaic; FVSI; Economic Load Dispatch; DEIANT Optimization***

I. INTRODUCTION

The 11th Malaysia Plan (11MP 2016 – 2020) is the final stage of the ambitious plan for Malaysia to become a developed nation by 2020. The aim of the Malaysia Entry Point Projects (EPP) 10, building up renewable energy (RE) and solar power capacity is to leverage renewable energy as a feasible alternative to reduce Malaysia's dependence on fossil fuels, minimize carbon emissions, stimulate foreign direct investments, and contribute to job opportunity. In the National Renewable Energy Policy, solar power must provide at least 220MW to the total mix of capacity. A regulatory framework was also developed for the feed-in tariff (FiT) mechanism, which enables the sale of locally produced electricity to power utilities at fixed premiums for a certain period of time to assist the Government achieve its renewable energy targets [1].

According to [2] the challenges facing power utilities are to provide reliable power to customers has increased growth of load demand, technical constraints in power system and lack of active power generation. In addition, increased demand for load from the commercial, residential and industrial sectors may leads to voltage instability in power system network. This effect will cause voltage collapse. Therefore, a variety of methods have been used towards ensure the voltage stability can be maintained. Several method have been introduced towards improve voltage stability in power system is by integrating RE such as solar photovoltaic into the power system. Although, an integration of RE into a power system causes certain technical effects such as voltage instability, flicker effect and harmonic voltages and current [3]. This is because the initial designs of an existing power system network were not integrating with any RE including solar photovoltaic. So, the small-scale solar photovoltaic may not have an effect on this network but large-scale solar photovoltaic integration could raise several technical problems on power quality and power system stability to power system. Stability of the power system has been a major concern where the focus is on voltage stability. Voltage stability is defined as the power system's ability to maintain a steady voltages at all buses in the system after experiencing some form of interference that leads to a voltage collapse [4].

Voltage instability occurs when the system generation fails to meet the load demand in the system [5]. Therefore, inappropriate integration of solar photovoltaic in random locations can cause power losses and voltage instability. So, this research highlightsolar PV placement and sizing for line stability enhancement and optimal operating cost.

II. LITERATURE REVIEW

As stated in [6] voltage stability indices calculate a numeric value from the power flow solution (PFS) that indicates the voltage stability state of the power system. The previous voltage stability indices were based on Jacobian matrix. However, this method cannot precisely estimate the voltage collapse point because of non-linearity near the collapse point. Next voltage stability indices developed in [7] calculated index based on artificial neural network (ANN), which is to address voltage security. This method becomes more complex and not suitable for the large power system. Others voltage stability index develops such as L-index based on load flow solution, is inaccurate when loads are not

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type of constant power. Line stability index (LMN) index is to evaluate the critical condition of lines. Line stability factor (LQP) index was developed that used for proving the voltage stability state of lines via load flow solution. This research employs FVSI as voltage stability indicator, as discussed further on the following section.

Fast voltage stability index (FVSI) suggested by [8] , was used to predict the voltage collapse point and contingency rankings of critical lines. The study [9] conclude that the voltage stability analysis procedure carried out using FVSI is efficient in defining the critical line referred to a critical outage, bus, the load ranking in the power system and weak bus beside. The highest FVSI value indicates a sensitive line referring to the bus, while the lowest reactive power loading shows the weak bus in the power system. This research uses FVSI to analyze the situation of voltage stability before and after the implementation of solar photovoltaic in a power system.

According to [10] the author highlight the researchers have proposed various intelligent technique optimization algorithm for example particle swarm optimization (PSO), non-dominated sorting genetic algorithm, ant colony optimization (ACO), and differential evaluation immunized ant colony optimization (DEIANT) and others technique to obtain ELD. In this research economic load dispatch is conducted to analyze the total loss and the total cost of the power system before and after the implementation of solar photovoltaic. The study conclude in [11] DEIANT is proposed as the optimization device to calculate the operating cost of power system with the integration of solar PV system. Solar PV integration significantly reduces fuel cost, as the technology will support the operation of existing conventional generators. From the study it can be concluded that DEIANT successfully optimizes ELD with photovoltaic integration. In this research DEIANT is proposed to optimize operating costs through optimal placement and sizing of solar PV.

III. METHODOLOGY

In this research, the economic dispatch of generation for minimization of the total operating cost and loss will be evaluated by using MATLAB. By referring to Table I the IEEE 26-Bus system will be used as test systems for simulation. The reactive power will be increase gradually. FVSI will be run for determined the strongest and weakest line. The line that exhibits FVSI closed to 1.00 implies that it is approaching its instability point. PV would be randomly installed at load bus as a solution to solve the voltage instability[12].

In this chapter, the modeling methodology will be defined with the modeling of the test system, the PV data output randomly placing, ELD and optimization will be described in Fig. 1 shown the research flow of this research.

Table. I Distribution of the generators capacity total static load in the IEEE 26-Bus system

Bus no	PGen(MW)	QGen (Mvar)
1	51	41
2	22	15
3	64	50
4	25	10
5	50	30
26	40	20

Table. II Cost Coefficient of IEEE 26-Bus system

Generators	a	b	c
G_1	240	$7.0P_1$	$0.0070P_1^2$
G_2	200	$10.0P_2$	$0.0095P_2^2$
G_3	220	$8.5P_3$	$0.0090P_3^2$
G_4	200	$11.0P_4$	$0.0090P_4^2$
G_5	220	$10.5P_5$	$0.0080P_5^2$
G_{26}	190	$12.0P_6$	$0.0075P_6^2$

Table. III Generator Real Power Limit of IEEE 26-Bus system

Generators	Minimum MW	Maximum MW
G_1	100	500
G_2	50	200
G_3	80	300
G_4	50	150
G_5	50	200
G_{26}	50	120

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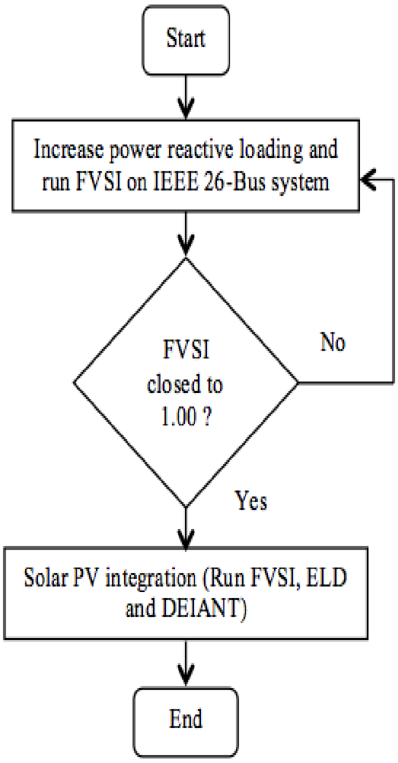

Fig. 1 Research Flow

A. Fast Voltage Stability Index (FVSI)

A study by [8], has derived Fast Voltage Stability Index (FVSI) to measure voltage stability of lines in power system. FVSI use mathematic formulation and implemented in MATLAB. FVSI is formulated based on 2-bus power system model as shown in Fig. 2:

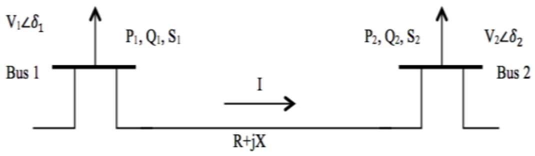

Fig. 2 2-Bus single line power system model

Where:

V_1, V_2 = Voltage on sending and receiving buses

P_1, Q_1 = Active and reactive power on the sending bus

P_2, Q_2 = Active and reactive power on the receiving bus

S_1, S_2 = apparent power on sending and receiving buses

= angle different between sending and receiving buses

$$FVSI_{ij} = \frac{4{Z_{ij}}^2 Q_j}{{V_1}^2 X_{ij}} \quad (1)$$

Where;

Z_{ij} = line impedance
X_{ij} = line reactance
V_i = voltage at the sending end
Q_j = reactive power at the receiving end

B. Solar PV

In this research, the Solar PV output and capacity has provided in [13] will be use as a variation of PV integrated to instability buses. The data of solar irradiance as shown in table IV explained on the penetrations of solar PV that categorized in accordance to the solar irradiation level.

Table. IV Summary of solar PV output power

No.	Irradiance (W/m^2)	Solar PV Output (MW)				Penetration Status
		10	20	40	100	
1	586	5.708	11.412	22.807	56.826	HIGH
2	470	4.475	8.941	17.891	44.652	AVG
3	112	0.859	1.734	3.485	8.721	LOW

C. Economic Load Dispatch

In this study, ELD is conducted by integrating four types of photovoltaic into the power system. The purpose is to reduce the operating cost that normally is directly proportional to fuel cost. So, ELD is conducted to determine the optimal and sizing solar PV to install in the 26-Bus system. The total operating cost is calculated by using the following quadratic function in (2) are taken from [11].

$$Cost_{GEN} = \sum_{i=1}^{n} C_i P_i = \sum_{i=1}^{n} a_i + b_i P_i + c_i {P_i}^2 \quad (2)$$

Where $Cost_{GEN}$ is the total fuel cost, C_i is the fuel cost of generating P_i amount of output power. a_i, b_i and c_i is the fuel cost coefficient for P_i. The total generated power should equal to the total load demands, P_D plus power losses, P_{loss} as in (3);

$$\sum_{i}^{n_g} P_i = P_D + P_{loss} \quad (3)$$

The power loss is calculated by using in (4);

$$P_{loss} = \sum_{i}^{n} \sum_{i}^{n} P_i B_{ij} P_j + \sum_{i}^{n} B_{0i} P_i + B_{00} \quad (4)$$

Where B_{ij}, B_{0i}, and B_{00} are the elements of loss coefficient matrix. In (5) satisfying the inequality constraint of generation limits for each unit:

$$P_{i(min)} \leq P_i \leq P_{i(max)} \quad (5)$$

Where $P_{i(min)}$ and $P_{i(max)}$ are the minimum and maximum generating limit.

Based on Power balance equation [14], the relationship between load demand, P_D generated power, P_i and power output of the solar, P_V is equated as in (6),

$$\sum_{i}^{n_g} P_i + P_{V(Solar\ PV)} = P_D \quad (6)$$

The relationship between the total cost for the initial operating condition and the total cost with optimal dispatch is equated as in (7),

$$\$/h = Total\ Cost\ Initial - Total\ Cost\ Optimal\ Dispatch \quad (7)$$

Total annual saving is equated in (8),

$$Total\ Annual\ Saving = \frac{\$}{h} * (8760) \quad (8)$$

D. Differential Evolution Immunized Ant Colony Optimization

In this research, DEIANT colony is apply as an optimization technique. DEIANT flowchart is shown in Fig. 3 and discussed briefly as follows:

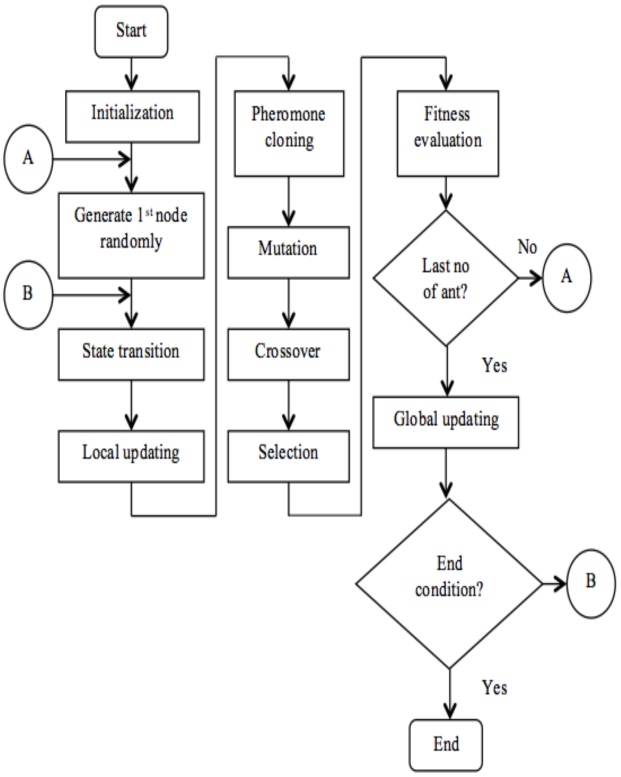

Fig. 3 DEIANT Flowchart

The following are DEIANT processes:

1) Initialization: Firstly, the nodes and the numbers of ant will be set to five. To produce a desirable, a small number of search ants with a small number of nodes are enough. Then, initialized the cloning and mutation coefficient.

2) Ant Tour: Fig 3 represents the random behavior of ant touring process. This process called permutation strategy. In this process, the ant will hold new exploration and select the node in tour. Different tour will be produced by different ants. The shortest path produces by ant which is the finest solution, will be put through towards the cloning process. In this study, the shortest path is produced by the summation of permutation that produces the lowest number of tours. Permutation process represent in (9) and (10).

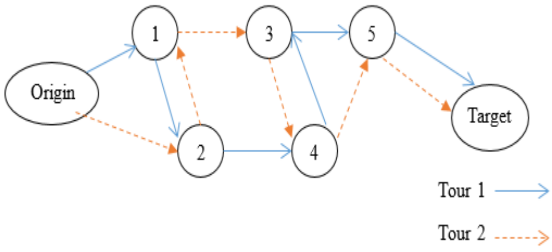

Fig. 3 The random behavior of ant touring process

$$n! = n^1, n^2, n^3 \ldots n^m \quad (9)$$

$$\sum_{m-1}^{m} n = n^1 + n^2 + n^3 \ldots . + n^m \quad (10)$$

Where,

n : number of nodes to be generated

n^1, n^2, n^3, n^m :generated node

m : m^{th} number of nodes

3) Tour Cloning: The cloning process will determine the selected tour. Depending on the initialized cloning coefficient, the process will replicate the selected tour. In search of the desired path, the cloning process is requiring by compensating the number of small search agents (ants). Through this cloning process the number of ants is reduced but the variety of solutions may increase. Fig. 4 shown the simple cloning process start from the original tour that will be cloned into several identical copies called cloned tour. Then, the cloned tour will be mutated.

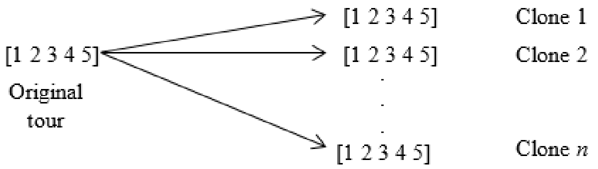

Fig. 4 Cloning Process

4) Tour Mutation: Gaussian or Normal distribution will be use in order to mutated the cloned tour. Refer to (11), Gaussian distribution is applied in the mutation process. The element of the cloned tour will be altering through this mutation process.

$$X_{i+m} = X_{i,j} + N\left(0, \beta\left(X_{jmax} - X_{jmin}\right)\right) . \frac{f_i}{f_{max}} \quad (11)$$

Where,

X_{i+m} : Mutation function

X_{jmin} : Smallest node number

X_{jmax} : Largest node number

f_i : Travelled distance

f_{max} : Maximum distance

In this mutation process, variation of ant tour will be increased and varieties of samples are going to be selected. The variation of ant tour depends on initial mutation coefficient. The mutated tour will be called as offspring tour and the cloned on as parent tour.

5) Crossover: Fig. 5 showing the crossover process, which is combination of parent and offspring tours in a single matrix. This crossover process later will be conducted in order to enhance the tour's variation.

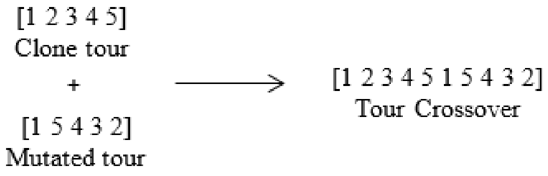

Fig. 5 Crossover Process

6) Tour Selection: Elements of a crossover-matrix arranged in descending order. The best elements are the best solution that will be compute for objective function.

7) Objective Function Calculation: The best element will be the one has lowest evaporative point. The objective function is solving by calculating control variable, as shown in (12).

$$X = \frac{d}{d_{max}} . X_{max} \qquad (12)$$

Where:

d : distance of ant tour
d_{max} : maximum distance
X_{max} : the maximum value of

The value of x will be taken as the multiplier to the output of the generator for ELD computation.

8) Termination: DEIANT process is halted when the best solution is obtained, or the maximum iteration is fully met. In this research, DEIANT is used to obtain an optimal placement and sizing of PV for operating cost minimization..

IV. RESULT AND DISCUSSION

This chapter provided a comprehensive result to obtain an optimal placement and sizing of solar PV for stability enhancement and operating cost minimization. The analysis on the power system stability under load variations at bus 9 using FVSI as stability indicator shown FVSI result is approaching 1. The FVSI of bus 9 increases proportionally with the increment in reactive power loading. Therefore, we can conclude that increasing in load demand will cause voltage instability to the power system. However, the purpose of appearance in this paper, only results on 350Mvar at bus 9 are given. Integrated solar PV at bus 9 identified the FVSI is start to reduced especially on the highest solar PV output power (solar PV with 100MW capacity) at highest penetration status. Looking back at the impact of solar PV towards the power system, the penetration of solar PV did improve the stability of the system. The results shown, the total cost and the total loss are starting to reduce depending on size and irradiance level of solar PV. The total demand, total different cost and total annual saving also have been analysis. It is prove that DEIANT successfully optimize the operating cost and the total loss of the IEEE 26-Bus test system.

A. Fast Voltage Stability Index (FVSI)

This study is conducted to determine the best PV size to install in the 26-Bus test system that can enhance the test system voltage stability under worse case condition. For this power system, the maximum loading is 350Mvar. By referring to table IV, the PV will be sized to four different power capacities; 10MW, 20MW, 40MW and 100MW. Each of the PV output power is divided into three irradiance level; lowest (LOW), average (AVG) and highest (HIGH) irradiance level. Tests were conducted by injected the solar PV with capacity 10MW, 20MW, 40MW and 100MW into the power system. The results for FVSI values obtain at reactive power loading at bus 9 set to 350Mvar are tabulates in Table V. The table tabulates the FVSI results for five weakest lines such as line 9, line 10, line 18, line 20 and line 27. It is observed that at the solar PV 100MW high penetration status, the FVSI values for line 9, line 10, line 18, line 20 and line 27 are decrease their values from 0.2027, 0.1361, 0.2888, 0.2534 and 0.1184 to 0.1855, 0.1125, 0.1862, 0.2441 and 0.1120 respectively. At this point, line 18 gives the lowest comparison FVSI value of 0.1862. It is also observe that as the solar PV increases by penetration status, the FVSI results evaluated for each line starts to decrease. This would mean that solar penetration status would cause the power system to be closer to its stability.

Table. V FVSI result for Q_9=350Mvar with PV variations penetration status

Penetration status	PV output power (MV)	FVSI values				
		Line 9	Line 10	Line 18	Line 20	Line 27
Without PV	**NA**	**0.2027**	**0.1361**	**0.2888**	**0.2534**	**0.1184**
10MW LOW	0.859	0.2027	0.1358	0.2870	0.2536	0.1184
10MW AVG	4.475	0.2027	0.1344	0.2786	0.2545	0.1182
10MW HIGH	5.708	0.2027	0.1339	0.2755	0.2547	0.1182
20MW LOW	1.734	0.2027	0.1354	0.2850	0.2539	0.1183
20MW AVG	8.941	0.2027	0.1328	0.2669	0.2549	0.1180
20MW HIGH	11.412	0.2026	0.1319	0.2600	0.2549	0.1179
40MW LOW	3.485	0.2027	0.1348	0.2810	0.2543	0.1183
40MW AVG	17.891	0.2026	0.1298	0.2415	0.2543	0.1177
40MW HIGH	22.807	0.1856	0.1200	0.2301	0.2454	0.1128
100MW LOW	8.721	0.2027	0.1328	0.2675	0.2549	0.1180
100MW AVG	44.652	0.1855	0.1147	0.1895	0.2440	0.1122
100MW HIGH	**56.826**	**0.1855**	**0.1125**	**0.1862**	**0.2441**	**0.1120**

In order to identify the FVSI results after PV placement for lowest irradiance level in the system, the FVSI results from Table V was extracted on the chart as shown in Fig. 5.

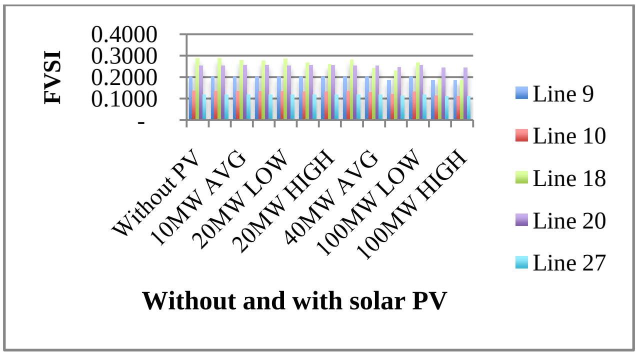

Fig. 5 FVSI results for Q_9=350Mvar reactive power loading without and with different penetration status of solar PV

B. Simulation 2: Economic Load Dispatch for 26 bus test system worst case

Table VI tabulates the results of total generation cost and total system loss for the condition without solar PV and with solar PV 10MW, 20MW, 40MW and 100MW is injected into the test system at 350Mvar loading. For the condition without solar PV, the total generation cost initial operating condition is approximately 16,233.93 $/h and the total system loss is approximately 60.20MW. The total generation cost with optimal dispatch of generation is 15,548.00 $/h and the total system loss is approximately 20.13MW. Based on the Table VI, it could be seen that when four types of solar PV is injected into the power system, the total generation cost and total system loss seems to be much lower compared to the test system without solar PV. For example when 100MW HIGH is injected into the power system, the total generation cost initial operating condition is approximately 15,273.07 $/h and the total system loss is approximately 19.34MW. The total generation cost with economic load dispatch of generation is 14,787.00 $/h and the total system loss is approximately 19.34MW.

Table. VI Total system loss and total generation cost, initial operating condition and optimal dispatch (350Mvar loading)

Without and With PV	Total System Loss (MW) initial operating condition	Total System Loss (MW), optimal dispatch	Total Generation Cost, ($/h) initial operating condition	Total Generation Cost, ($/h) optimal dispatch
Without PV	60.20	20.13	16,233.93	15,548.00
10MW LOW	59.30	20.12	16,214.17	15,537.00
10MW AVG	55.72	20.05	16,133.88	15,488.00
10MW HIGH	54.57	20.03	16,107.49	15,471.00
20MW LOW	58.41	20.10	16,194.32	15,525.00
20MW AVG	51.72	19.97	16,040.49	15,427.00
20MW HIGH	49.67	19.93	15,991.25	15,394.00
40MW LOW	56.67	20.07	16,155.42	15,501.00
40MW AVG	44.82	19.81	15,869.30	15,306.00
40MW HIGH	41.56	19.87	15,782.84	15,243.00
100MW LOW	51.90	19.97	16,044.95	15,430.00
100MW AVG	32.85	19.52	15,446.65	14,950.00
100MW HIGH	32.16	19.34	15,273.07	14,787.00

Based on Table VII, when four types of solar PV are installed into the power system, load demand is re-dispatched among the generators such as G_1, G_2, G_3, G_4, G_5 and G_{26} and the solar PV units. Promptly, the loads simultaneously supply by the existing conventional generators and the solar PV units. For example, the result for load demand without solar PV is 1263MW, after solar PV 100MW HIGH is installed into the power system; generators only supply 1206.20MW from the load demand another load demand approximately 56.826MW is supplied by solar PV unit.

Table. VII Total optimal dispatch, total demand, total saving $/h and total annual saving for initial operating condition and optimal dispatch (350Mvar loading)

Without and With PV	Total Optimal Dispatch of Generation (Pgtt), MW	PV Output Power, MW	Total Demand, (Pdt), MW	Total Different Cost before and After, ($/h)	Total Annual Saving Cost hr/year, ($/h)
Without PV	1283.10	-	1263	685.93	6,008,723.30
10MW LOW	1282.30	0.859	1262.10	677.17	5,932,007.71
10MW AVG	1278.60	4.475	1258.50	645.88	5,657,906.24
10MW HIGH	1277.30	5.708	1257.30	636.49	5,575,683.32
20MW LOW	1281.40	1.734	1261.30	669.32	5,863,276.19
20MW AVG	1274	8.941	1254.10	613.49	5,374,164.15
20MW HIGH	1271.50	11.412	1251.60	597.25	5,231,904.60
40MW LOW	1279.60	3.485	1259.50	654.42	5,732,705.30
40MW AVG	1264.90	17.891	1245.10	563.30	4,934,500.16
40MW HIGH	1260.10	22.807	1240.20	539.84	4,728,972.60
100MW LOW	1274	8.721	1254.30	614.95	5,386,989.04
100MW AVG	1238	44.652	1218.30	496.65	4,350,690.73
100MW HIGH	1226	56.826	1206.20	486.07	4,257,970.29

Furthermore, for power system without solar PV, Table VII also tabulates this results in a savings of 685.93 $/h and the total annual savings is approximately 6,008,723.30 $/h. However, when four types of solar PV are installed into the power system this results in a saving of power system and the total annual savings starts to decrease. For example, for 100MW HIGH, this results in a savings of 486.07 $/h with the total annual savings is approximately 4,257,970.29 $/h.

C. Simulation 11: 50Mvar loading without PV and with PV High irradiance level

Finally, the comparisons are made between optimal dispatch without PV and with PV during high irradiance level of PV with DEIANT, Table VIII and IX tabulates DEIANT results successfully minimize the total cost and the loss the total cost.

Table. VIII DEIANT results with PV1 and PV2 with high penetration status

Technique	Optimal Dispatch Without PV	PV1		PV2	
		PV Capacity = 10MW		PV Capacity = 20MW	
		PV Output = 5.708MW		PV Output = 11.412MW	
		Optimal Dispatch	DEIANT	Optimal Dispatch	DEIANT
G_1 (MW)	447.6919	446.5479	425.22	445.4054	488.21
G_2 (MW)	173.1938	172.3457	181.7288	171.4988	133.1697
G_3 (MW)	263.4859	262.5967	249.2592	261.7088	274.9143
G_4 (MW)	138.8143	137.7844	113.5205	136.7563	106.2727
G_5 (MW)	165.5883	164.5837	184.4786	163.579	164.1099
G_{26} (MW)	87.026	86.1391	111.4889	85.2527	94.4657
Total Cost ($/h)	15,448.00	15,371.00	15,326.19	15,294.00	15,282.81
Total Loss (MW)	12.80	12.71	8.40	12.61	9.55

For example, DEIANT computed the lowest total cost to 14,723.00 $/h and minimize the total loss to 8.64 when PV4 integrated into the power system.

Table. IX DEIANT results with PV3 and PV4 with high penetration status

Technique	Optimal Dispatch Without PV	PV3		PV4	
		PV Capacity = 40MW		PV Capacity = 100MW	
		PV Output = 22.807MW		PV Output = 56.826MW	
		Optimal Dispatch	DEIANT	Optimal Dispatch	DEIANT
G_1 (MW)	447.6919	443.1251	471.12	440.0786	494.33
G_2 (MW)	173.1938	169.8084	143.1027	156.5072	143.8065
G_3 (MW)	263.4859	259.9367	266.4623	255.9525	234.3811
G_4 (MW)	138.8143	134.7055	136.9146	128.5543	51.3617
G_5 (MW)	165.5883	161.5693	159.3413	157.7495	179.1862
G_{26} (MW)	87.026	83.4816	72.9469	79.0691	111.7541
Total Cost ($/h)	15,448.00	15,140.00	15,117.31	14,683.00	14,723.73
Total Loss (MW)	12.80	12.43	9.70	11.74	8.64

It means that, at PV4 with PV capacity 100MW HIGH penetration produced the lowest total cost and total loss compared to PV1, PV2 and PV3.

V. CONCLUSION

This research is a solar PV placement and sizing for line stability enhancement and optimal operating cost can improve stability and reduce operating costs. This research was conducted on IEEE 26-Bus system. The system contains with six generators. The objectives are to analyze power system stability under load variations using FVSI as stability indicator, to evaluate the voltage stability before and after solar photovoltaic implementation using FVSI and to determine optimal placement and sizing of solar photovoltaic and for enhance power system stability and minimized operating cost. DEIANT is used to optimize the operating cost. The voltage stability analysis carried out using FVSI is capable to evaluate and determining the critical line on IEEE 26-Bus system after gradually increase the reactive power loading at bus 9. Comparative studies for FVSI were also conducted between the FVSI results obtained before and after PV implementation. This FVSI successfully reduced after PV implementation. In this research, the DEIANT algorithm is proposed to optimize economic dispatch before and after PV implementation. This technique is used to compare the total cost and total loss between optimal dispatches without PV, with PV with DEIANT. DEIANT technique is successfully reduced the total cost and the total loss of PV. So it can be concluded PV with high irradiance level is able to stabilize the power system at minimal operating cost.

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REFERENCES

1. KeTTHA, “National Renewable Energy Policy,” Natl. Renew. energy Policy, no. November, p. 90, 2008.
2. Z. KAMARUZZAMAN, “Effect of grid-connected photovoltaic systems on static and dynamic voltage stability with analysis techniques - a review,” Przegląd Elektrotechniczny, vol. 1, no. 6, pp. 136–140, 2015.
3. J. Paska, P. Biczel, and M. Kłos, “Technical and economic aspects of electricity storage systems co-operating with renewable energy sources,” 2009 10th Int. Conf. Electr. Power Qual. Util. EPQU’09, pp. 1–6, 2009.
4. I. Musiri and T. K. Abdul Rahman, “On-line voltage stability based contingency ranking using fast voltage stability index (FVSI),” Proc. IEEE Power Eng. Soc. Transm. Distrib. Conf., vol. 2, no. ASIA PACIFIC, pp. 1118–1123, 2002.
5. S. E. E. Profile, “Stability Improvement of Power System by Using PI &,” no. March 2013, 2018.
6. S. Ratra, R. Tiwari, and K. R. Niazi, “Voltage stability assessment in power systems using line voltage stability index,” Comput. Electr. Eng., vol. 70, pp. 199–211, 2018.
7. D. Devaraj and J. Preetha Roselyn, “On-line voltage stability assessment using radial basis function network model with reduced input features,” Int. J. Electr. Power Energy Syst., vol. 33, no. 9, pp. 1550–1555, 2011.
8. I. Bin Musirin, “Universiti Teknologi MARA New Techniques for Voltage Stability Assessment and Improvement in Power System,” 2003.
9. I. Musirin and T. K. Abdul Rahman, “Novel fast voltage stability index (FVSI) for voltage stability analysis in power transmission system,” 2002 Student Conf. Res. Dev. Glob. Res. Dev. Electr. Electron. Eng. SCOReD 2002 - Proc., no. October 2018, pp. 265–268, 2002.
10. S. K. Mishra and S. K. Mishra, “A Comparative Study of Solution of Economic Load Dispatch Problem in Power Systems in the Environmental Perspective,” Procedia Comput. Sci., vol. 48, no. Iccc, pp. 96–100, 2015.
11. N. A. Rahmat, N. F. A. Aziz, M. H. Mansor, and I. Musirin, “Optimizing Economic Load Dispatch with Renewable Energy Sources via Differential Evolution Immunized Ant Colony Optimization Technique,” Int. J. Adv. Sci. Eng. Inf. Technol., vol. 7, no. 6, p. 2012, 2017.
12. S. K. Nandha Kumar and P. Renuga, “FVSI based reactive power planning using evolutionary programming,” 2010 IEEE Int. Conf. Commun. Control Comput. Technol. ICCCCT 2010, pp. 265–269, 2010.

13. A. W. H. Sie, I. Z. Abidin, and H. Hashim, "A methodology to determine suitable placement of solar photovoltaic sources in the transmission system taking into account Voltage Stability Index (VSI)," Conf. Proceeding - 2014 IEEE Int. Conf. Power Energy, PECon 2014, pp. 226–230, 2014.
14. W. A. Augusteen, S. Geetha, and R. Rengaraj, "Economic dispatch incorporation solar energy using particle swarm optimization," 2016 3rd Int. Conf. Electr. Energy Syst. ICEES 2016, pp. 67–73, 2016.