VOLTAGE STABILITY IN DISTRIBUTION SYSTEM BY USING WIND DISTRIBUTED GENERATION WITH OPTIMAL LOCATION

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ABSTRACT :

The greater demand than the generation at present time ,distributed generation (DG) has been experiencing a rapid development in a global scale. The size of wind farm increasing quickly and a large amount of renewable distributed generation is integrated into the grid daily. The impact of DG units on the voltage stability margins has become significant. Optimization techniques are tools which can be used to locate the DG units in the system. So as to utilize these units optimally within certain limits and constraints, the impacts of DG units issues, such as voltage stability and voltage profile, can be analyzed effectively.

This paper presents the modeling and simulation of schemes with wind energy conversion systems (WECS) for mitigation of voltage dips within a short period of time on power system. Also a method of locating DG units so as to improve the voltage stability margin. The load and renewable DG generationprobabilistic nature are considered in this study. The proposed method starts by selecting candidate buses into which to install the DG units on the system, prioritizing buses which are sensitive to voltage profile and thus improve the voltage stability margin. The DG units' placement is formulated using mixed-integer nonlinear programming, with an objective function of improving the stability margin.

Keywords —Distributed generation (DG), wind energy conversion systems, voltage dips ,optimum power flow, voltage profile, voltage stability.

I. INTRODUCTION

One of the most important infrastructures in any country is energy. This has become a basic need for man to live. As the population over the years have increased, and the demands forelectricity have grown, utilities around the world, face the problem of electrification and delivery of reliable and quality electricity. Due to various pressures such as regulatory bodies, cost of constructing large power plants, environmental impact issues, competitive markets, and the concept of centralized generation is becoming more difficult to implement. As a result of these, there is a strong need for cleaner renewable energy sources. Distributed generation (DG) is one of the new technologies that are bracing electrical networks around the world. There is a need to diversify the energy sources to renewable energy such as wind, solar and small hydro power for sustainable energy development. This will reduce the effect of greenhouse gas produced from burning fossil fuel that is manifesting more and more and subjectingthe environment to global threat. When these renewable energies are implemented as Distributed Generation (DG) it is expected to play an important role in the operation of power network. In a normal, healthy power network, the power generated must be equal to the load demand at any particular point oftime. Any reactive power imbalance in the system disturbs the voltage at the load points and the voltage profiles along the network. This imbalance or sudden change causes unexpected drop in the voltage in a power network and is known as voltage dip.

II. VO LTAGE DIP PHENOMENA

Voltage dip has been a burning technical issue in weak power grid, in the past few years resulting in poor power quality and stability. In recent times many industries and other consumers of electric power have lost so much revenue due to this difficult situation. Weak grids are usually found i n most remote places where the feeders are long and operated at a medium voltage level. The grids in these places are usually designed for relatively small lo ads. When the design load is exceeded the voltage level will be below the allowed minimum voltage which leads to voltage dip in many cases.

Voltage dip is a reduction in voltage magnitude below a dip magnitude threshold with duration typically from several cycles to several seconds. It is also defined as a sudden short duration reduction of the voltage at the point of supply (nominal system voltage) to a value between the ranges of 10% to 90% of nominal voltage magnitude and with duration from 10ms up to one minute. It might originate from switching of motors, generator s, arc furnaces, transformer s or from short circuits faults in power transmission and distribution system. A voltage dip is characterized by its magnitude and duration. In most cases, fault types, source and fault impedance s define the dip magnitude, whereas fault clearing time defines the dip duration.

An example of a typical voltage dip is shown in Fig: 1. It commences when the declared voltage drops to a lower voltage than the threshold voltage V_{thr} (0.9 p.u. or 90 %.) at time T1, it continues up to T2 at which the voltage recovers to a value over the threshold value. The magnitude of the voltage dip is V_{dip} and its duration is T2-T1.

Many consumers have been using their own gadgets to solve the problem of voltage dips at their own premises. But this does not really solve the problem completely especially when there is a dip less than the gadget rating. At a very low voltage, voltage dip mitigation equipment such as voltage stabilizer can be used to deal with voltage dip. In this case, no energy storage mechanism is required. The automatic voltage stabilizers rely on generating full voltage from the available energy supply at reduced voltage during the dip. A Few examples include, electro-mechanical, Ferro-resonant or constant voltage transformer, electronic step regulators etc.

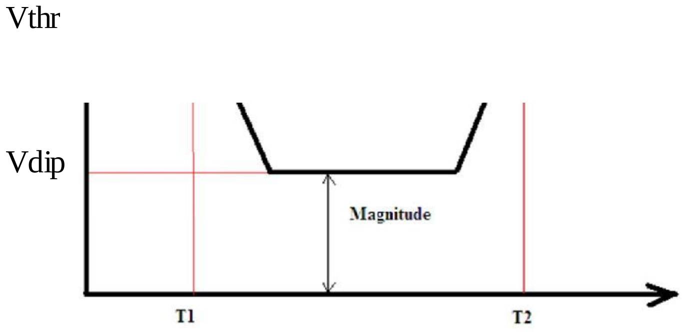

Fig:1 Voltage dip

In solving the problem of voltage dips and for keeping the voltage at its nominal value during the dip on the transmission and distribution power network, several methods or schemes have been proposed by various researchers. Many of these schemes utilize DG for improving the power quality, especially for mitigating voltage dip problems.

III. DEFINITION OF DISTRIBUTED GENERATION

In recent times the penetration of wind energy conversion systems (WECS) into the grid for clean energy generation is significantly increasing and consequently their impact on grid operation are becoming more and more important. Power electronic interfaced wind generators connected to the grid can inject harmonic current which might deteriorate the power quality of the power system network. It is well known that most wind generators also contribute to voltage disturbance on the grid, especially voltage dip. On the contrary distributed wind generators when properly integrated can also be used to mitigate voltage dips in a power network.

Most countries of the world have been trying to reduce the carbon dioxide emissions and generate electrical power through the use of renewable DG such as WECS, HP, solar photovoltaic, etc. In technical literature, the term DG is synonymous with on-site generation, dispersed generation, embedded generation or decentralized generation, and is generally defined as any generation which is connected directly into the distribution network, as opposed to the transmission network. It makes use of small-scale low carbon renewable and non-conventional power generation technologies the units are usually located close to the load being served.

Its main advantages according to research literature include elimination/reduction of greenhouse gases and carbon emissions, improved security of supply, reduction of grid losses, power quality support including voltage dip mitigation and reliability improvement. However, degree of DG penetration can also affect the power distribution system negatively and its impact might be change in voltage profile along the network, Overloading of lines and equipment leading to thermal overloading. There may also be Congestion on the system, power quality and reliability will be affected.

IV. IMPACT OF THE DG SIZE ON VOLTAGE STABILITY

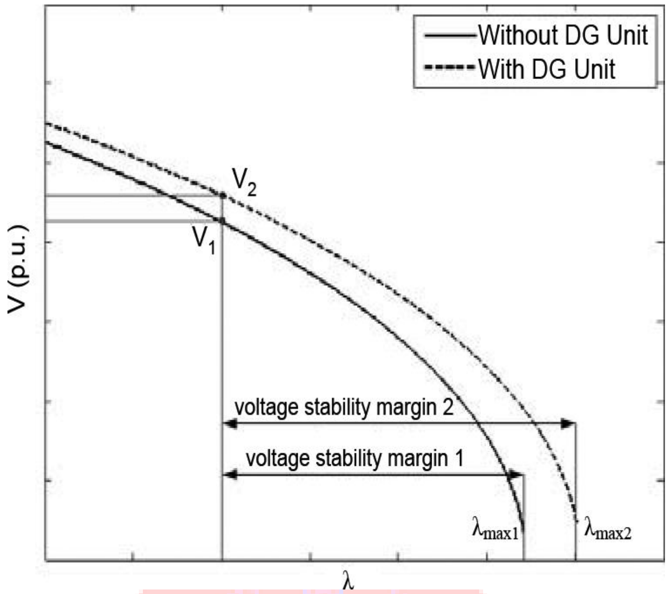

Fig. 2. Impact of a DG unit on maximum loadability and voltage stability margin

Voltage stability analysis has been presented by many techniques, including static and dynamic methods. The static technique can be analyzed by using the relation between the receiving power (P) and the voltage (V) at a certain bus in asystem which is known as a P-V curve or nose curve (seeFig. 1). The P–V curve is obtained by applying continuouspower flow method. The critical point(saddle-nodebifurcation point) in the P–V curve represents the maximumloading of a system. This point corresponds to a singularity ofthe Jacobian of the power flow equations. The stability margincan be defined by the MW distant from the operating point tothe critical point. The penetration of the DG units in a distribution system can increase or decrease the voltage stability margindepending on their operation at unity, lead or lag power factors.Currently most of the installed DGs are commonly connectedto operate at unity power factor to avoid interference with thevoltage regulation devices connected to the system.For this reason, this study assumes that all of the DG units areoperating at unity power factor. In addition, some utilities allowthe DG units to operate in fixed power factor mode ranging from0.95 lagging to 0.95 leading, a case study representing this condition is also considered.

Fig.2 visualizes the impact of a DG unit on voltage stability margin and maximum loadability. The x-axis represents λ, which is the scaling factor of the load demand at a certainoperating point (see (1)).λ varies from zero to the maximumloading. Due to real power injection of a DG unit, thenormal operating point of the voltage increases from V_1 to V_2,and at the same time the maximum loadability increases from λ_{max1} to λ_{max2}as

$$P_i = \lambda P_{0, I} \quad \text{.........................(1)}$$

$$Q_i = \lambda Q_{0, I} \quad \text{.........................(2)}$$

V. DG PLACEMENT PROBLEM FORMULATION

After the candidate buses are selected, allocating DG units within the system requires investigation interms of DG resources and their uncertainties. It also requiresmodeling the types of load and their criticality at each bus. Inaddition, placing the DG units in the most sensitive buses mightviolate the voltage limits or the capacity of the feeders, depending on the size of the DG units and the load demand of thesystem. Accordingly, this section proposes a method to placeDG units with an objective of improving the voltage stabilityof the system. This study is demonstrated in five scenarios.

• Scenario #1: this is a reference scenario, in which no DGunits are connected to the system (base case)

• Scenario #2: only dispatchable (non-renewable) DG units are connected.

• Scenario #3: only wind-based DG units are connected.

• Scenario #4: only PV DG units are connected.

• Scenario #5: a mix of dispatchable, wind-based, and PVDG units are connected.

In this formulation, the following assumptions are considered.

• More than one type of DG can be installed at the same candidate bus.

• The DG units are assumed to operate at unity power factor .In addition, a simulation for DG units that operates between 0.95 lead or lead power factor is presented

• All buses in the system are subjected to the same wind speed and solar irradiance. This assumption greatly simplifies the analysis.

• The penetration level is equal or less than 30%; referringto Ontario’s standard program, the maximum penetrationlevel is 30% of the maximum load.

The DG placement method is carried out as follows.

Step 1: Load and DG Units Modeling

The model is conducted as follows.

• Each year is divided into four seasons, and each seasonis being represented by any day within that season. These data are then utilized to generate for each season a typical day’s frequency distribution of the irradiance and windspeed measurements.

• The day which is representing the season is further subdivided into 24 1-h segments (time segments) each referring to a particular hourly interval of the entire season. Asa result, there are 96 time segments for the year (24 for each season). Considering a month to be 30 days, each time segment then has 270 irradiance and wind speed level data points (3 years 30 days per month 3 months per season).

• The mean and standard deviation for each time segment are calculated.

• The Beta and Weibull probability density functions are generated for each hour using the mean and standard deviation for each segment.

• The Beta and Weibull probability density functions are divided into states (periods) to incorporate the output power of the solar DG and wind-based DG units. The number ofstates is chosen carefully as a small number of states willaffect the accuracy, while a large number will increase theproblem’s complexity. In this paper, the state is adjusted to be 0.1 kW/m for solar irradiance and 1 m/s for wind speed.

- The corresponding output power of the PV module and wind turbine in each state are calculated using the PV module characteristics and wind turbine power performance curve.

Step 2: Load and DG Units Modeling

A. Objective Function

The DG placement and sizing with anobjective of increasing the voltage stability margin can be formulated by increasing the voltage of the system using DG units.The following equation is used to improve the voltage profile of the system:

$V_n = V_{P,\text{with DG}} / V_{P,\text{with out DG}}$ ……………………..(3)

Thus, it can be used to improve the voltage stability margin ofthe system. This equation is modified to include the probabilisticnature of the DG generation as in

$$\text{Maximize } V_{index} = \left(\sum_{n=1}^{N} V_n \, p \, r_n \right) /96 \quad \text{……………….(4)}$$

The highest V_{index} implies the best location for the installation of the DG units in term of improving the voltage profile.The following attributes show the impact of the DG units:

V_{index} $<$ DG units will worsen the voltage profile

$=$ DG units will not impact on the voltage profile

$>$ DG units will improve the voltage profile………(5)

B. Constraints

Power flow equations:

$$P_{Gn,1} + C(n,1)*P_{DG\,Di} + C(n,2)*P_{DG\,Wi} + C(n,3)*P_{DG\,Si} - C(n,4)*P_{Di} = \sum_{j=1}^{m} V_{n,i}*V_{n,i}*Y_{i,j}*COS(\theta_{ij}+\delta_{n,j}-\delta_{n,i}) \quad \text{…………….(6)}$$

$$Q_{Gn,1} - CI(n,4)*Q_{Dn,i} = -\sum_{j=1}^{m} V_{n,i}*V_{n,i}*Y_{i,j}*\sin(\theta_{ij}+\delta_{n,j}-\delta_{n,i}) \quad \text{…………….(7)}$$

Branch current equations:

$$I_{n,ij} = |Y_{ij}|*[(V_{n,i})^2+(V_{n,j})^2-2*V_{n,i}*V_{n,j}*\cos(\delta_{n,j}-\delta_{n,i})]^{1/2} \quad \text{…………….(8)}$$

Where $I_{n,ij}$ is the current in the feeder connecting buses i and j whereduring state n.

Slack bus voltage and angle (assumed to be bus 1):

$$V_{n,1}=1.025$$

$$\delta_{n,1}=0.0 \quad \text{…………….(9)}$$

Voltage limits at the other buses:

$$0.95 \leq V_{n,i} \leq 1.05 \qquad \ldots\ldots\ldots\ldots\ldots\ldots(10)$$

Feeder capacity limits:

$$0 \leq I_{n,ij} \leq I_{jmax} \qquad \ldots\ldots\ldots\ldots\ldots\ldots(12)$$

Maximum penetration on each bus:

$$P_{DG\,Di} + P_{DG\,Si} + P_{DG\,W} \leq 10MW \qquad \ldots\ldots\ldots\ldots\ldots\ldots(13)$$

The maximum penetration of DG capacity should not exceed 10MW at each bus of the candidate buses

Maximum penetration of DG units on the system:

$$\sum_{i=1}^{m} P_{DG\,Di} + \sum_{i=1}^{m} CF_W P_{DG\,Wi} + \sum_{i=1}^{m} CF_s P_{DGsi} \leq Y^* \sum_{i=1}^{m} P_{Di} \qquad \ldots\ldots\ldots\ldots\ldots\ldots(14)$$

where is the maximum penetration limit as a percentage of the peak load. For the penetration level not to exceed 30%, equals0.3.

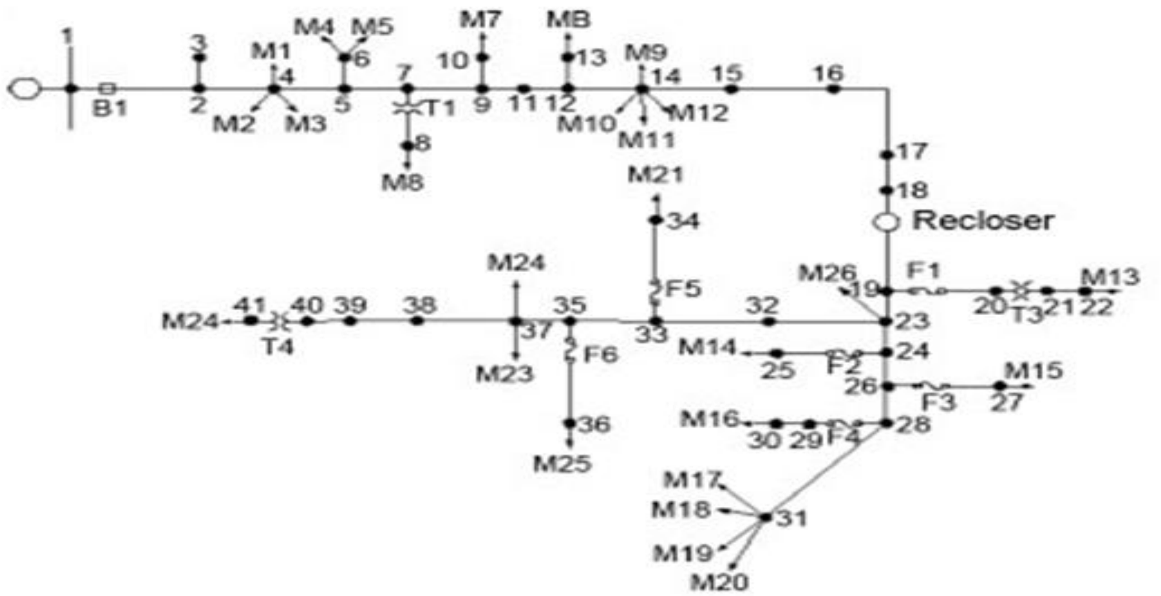

Fig. 3.Sistribution test system of 41 buses

VI. RESULTS

A. Results of Candidate Buses for the DG Units Installation In Fig. 4, the selection is achieved by developing 26 case studies (the cases are equal to the number of the system buses which are located in the main feeders). In each case, a DG unit is installed at a certain bus, and the changes of the system voltages are observed.

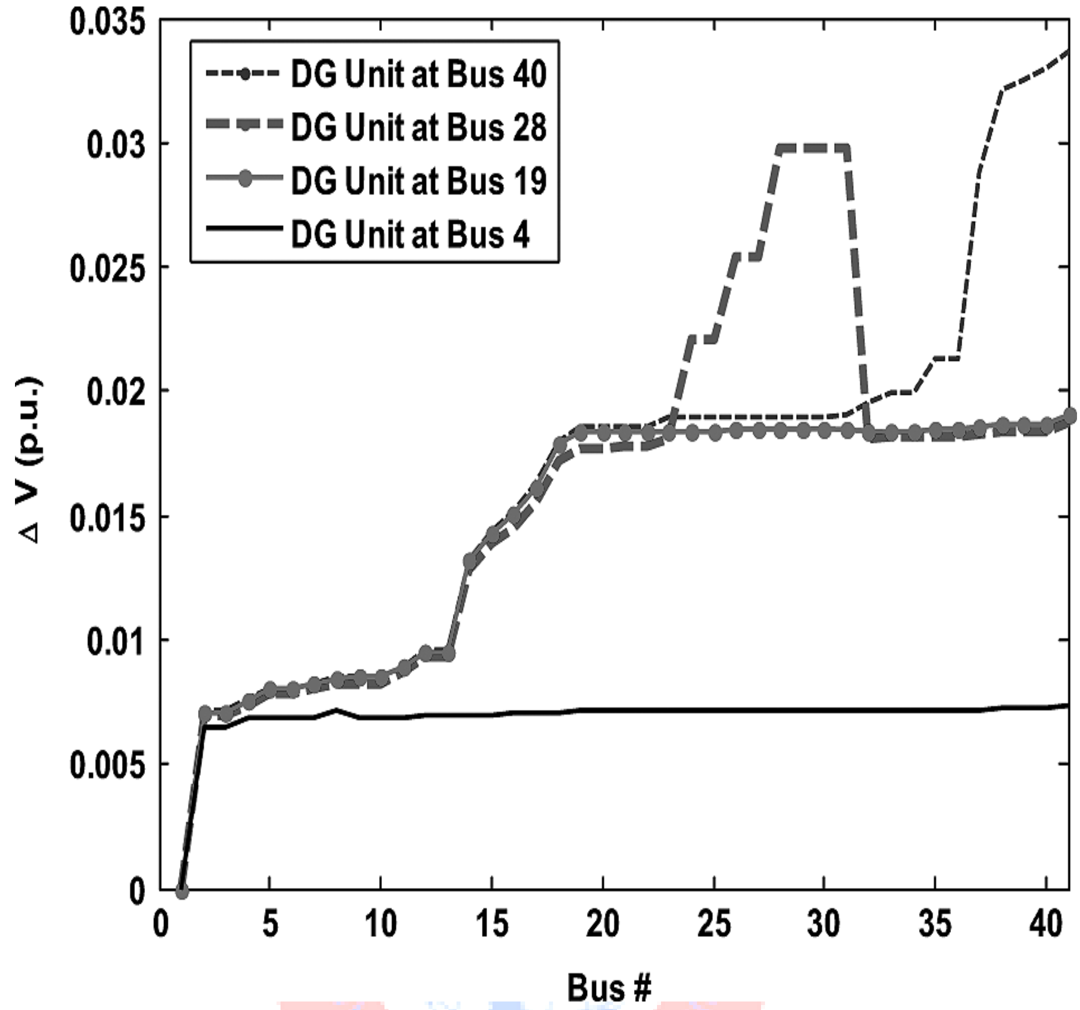

Fig. 4. Results of voltage sensitivity analysis (the penetration level is 30%).

B. Results of the Impact of the DG Units on Voltage Stability:

Fig.5show the changes of the maximum loadability of both studies. Placing a DG unit in bus 40 improves the voltage stability margin more than the other candidate buses because the voltage at bus 40 is more sensitive to the real power (see Fig. 3). Also, bus 41 has high load demand, therefore, placing the DG unit on bus 40 makes the upper stream feeder gain more capacity for power loading. However, if the DG unit is placed on bus 28, the feeders will gain less capacity because the load demand in its down stream low compared to bus 41. Therefore, when the DG power at bus 28 increases, the current reverses to the upper stream. In this situation, the feeder between buses 23to 41 will not gain extra capacity for power loading. Further-more, Fig. 5 shows the impact of two DG units. They are placed in bus 40 and 28. Both DG units are varied from 0 to 8 MW;thus, the total of generation for both units is 16 MW(approximately 100% of the penetration level). When the two DG units are added, the downstream feeders (from bus 23 to 31, and from buses 23 to 41), and the upstream feeder (from buses 1 to 23), gain more capacity. Therefore, this capacity is reflected in the increase of the voltage stability margin to. How-ever, this result is still lower than that of installing one DG unit

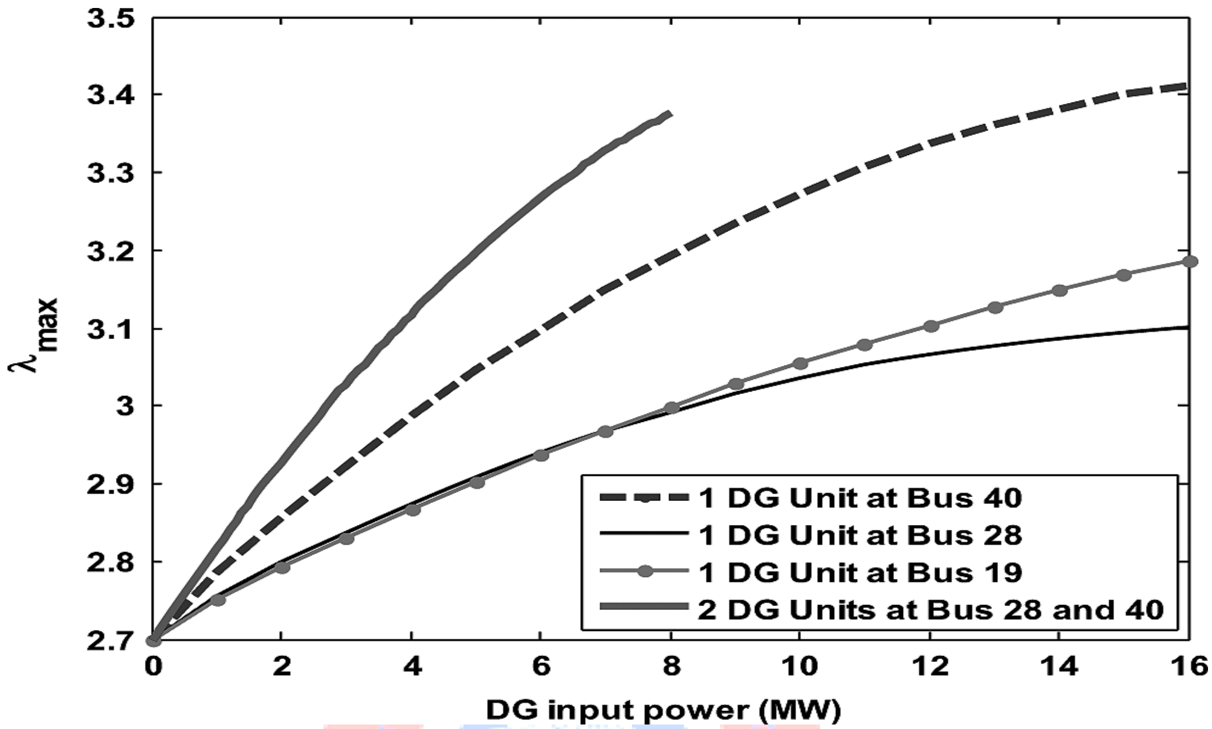

Fig. 5. Impact of the size of the DG units on maximum loading

TABLE I
RESULTS OF THE DG LOCATION AND SIZE, SCENARIOS (1–4)

Candidate buses	Scenarios			
	1	2	3	4
19	0	0	0	0
23	0	0	0	0
24	0	0	0	0
26	0	0	0	0
28	0	0	1.1 MW	1.55 MW
32	0	0	0	0
33	0	0	0	0
35	0	0	0	0
37	0	0	0	0
38	0	0	2.2 MW	1.92 MW
39	0	0	0	0
40	0	4.5 MW	6.6. MW	9.47 MW
Total size	0	4.5 MW	9.9 MW	12.91 MW

TABLE II
RESULTS OF THE DG LOCATION AND SIZE, SCENARIO (5)

Candidate buses	Scenarios		
	5		
	WIND (MW)	SOLAR (MW)	DISPATCHABLE (MW)
19	0	0	0
23	0	0	0
24	0	0	0
26	0	0	0
28	0	0.87	0
32	0	0	0
33	0	0	0
35	0	0	0
37	0	0	0
38	0	0	0
39	0	0	0
40	3.3	3.38	1.2
Total size	3.3	4.25	1.2

At bus 40(λ_{max}=3.404) Thus, applying optimization method can solve the problem of placement and sizing of the DG units to improve the voltage stability margin.

C. Results of the DG Sizes and Locations:

In Tables I and II, the simulation of the optimization formulation placed and sized the DG units in buses 40, 38, and 28. In all scenarios, the highest DG rating is placed in bus 40. This placement is reasonable because bus 40 is located at the far end of the distribution system and has low voltage profile. However, if theoptimization constraints of the voltage and current are violated,then the second option will be bus 38. Bus 28 is also sensitive tothe DG penetration as shown from Fig. 3. As results, the simulation has considered this bus for the DG placement and sizing. The total size of the wind DG units in scenarios 3 and 5 is lower than the solar units in scenarios 4 and 5. This result is logical since the capacity factor of the wind turbine is higher than the solar photovoltaic generator.Tables I and II show the results when the DG units are operating at unity power factor. On the other hand, the utilities that allow the DG units to operate in fixed power factor mode (0.95 lagging to 0.95 leading), needmore elaboration. In this case, the DG units will have more chance to improve the voltage stability margin if they are operating in leading power factor and supporting the system with reactive power. The sensitivity analysis of $\Delta V/\Delta Q$ is conducted to test the most sensitive buses asin

$$\Delta V=(J_{RQV})^{-1}\Delta Q \qquad \text{……………………(17)}$$

Where

$$Q_{G\,n,1}+C(n,1)*Q_{DG\,Di}+C(n,2)*\ Q_{DG\,Wi}+C(n,3)*\ Q_{DG\,Si}-C(n,4)*\ Q_{Dn,i}$$

$$= -\ {}_{j=1}^{m} V_{n,i} * V_{n,i} * Y_{ij} * \sin(\theta_{ij}+\delta_{n,j}-\delta_{n,i}) \ldots\ldots\ldots\ldots\ldots\ldots\ldots..(18)$$

The results show that the most sensitive buses are the samebuses as ofsensitivity as shown in Fig. 6, but withhigher magnitude ofdue to the high sensitivity of reactive power changes to the voltage profile of the system. In addition, the condition of operating DG units in fixed power factor mode (0.95 lagging to 0.95 leading) should be considered asconstraints in the formulation of the placement and sizing of theDG units. In addition, (9) should be modified to include thereactive power generation as in (17).

The simulation results of DG units that operate in fixed powerfactor mode (0.95 lagging to 0.95 leading) are included in thispaper. As given in Table III. These results show that the dispatchable DG units in scenario 1 are placed in bus 40. However, forthe wind in scenario 3 and solar in scenario 4, the higher ratingsof the DG units are placed in bus 19.

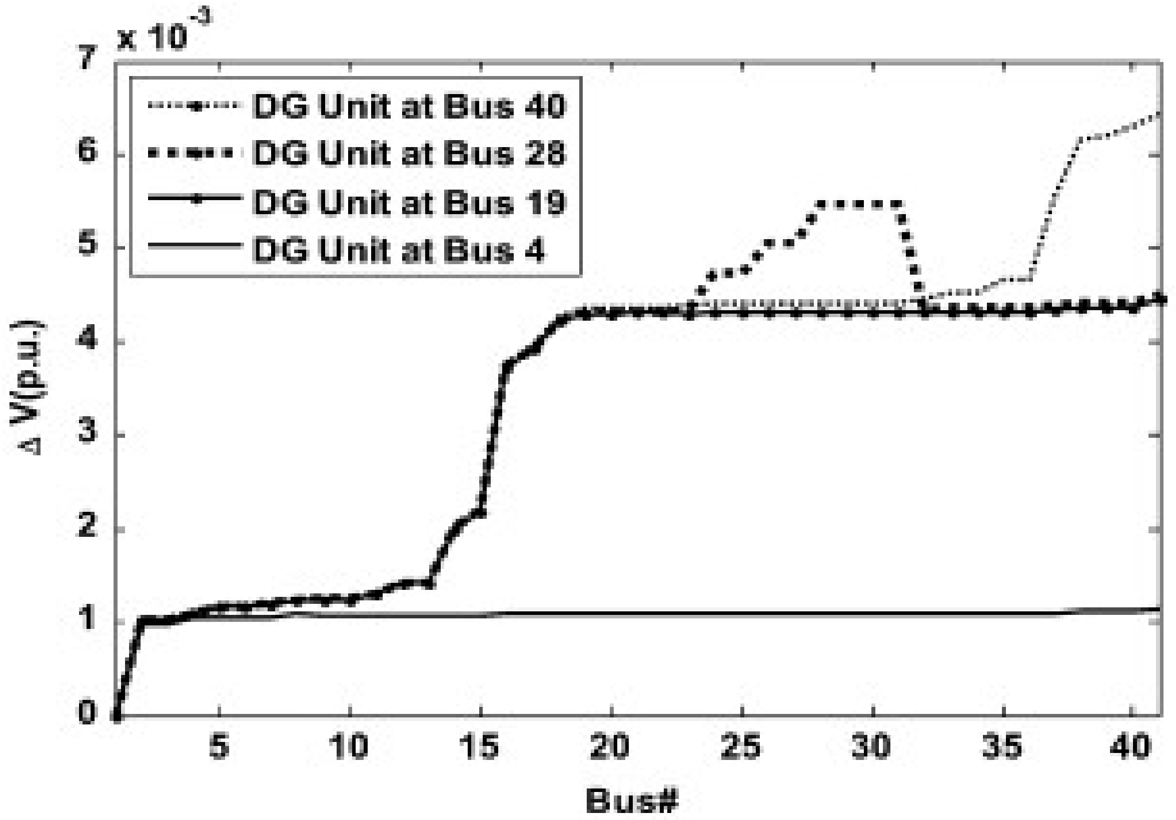

Fig. 6. Results of voltage sensitivity analysis ΔV/ ΔQ

TABLE III

RESULTS OF THE DG LOCATION AND SIZE, SCENARIOS WHEN DG UNITS OPERATES BETWEEN 0.95 LEAD OR LAG POWER FACTOR

Scenario	Type of DG	Location	Rating MVA	Power factor
1	Base case: No DG installed			
2	Dispatchable	bus 40	4.5	0.95 lead
3	Wind	bus 19 bus 40	8.8 1.1	0.95 lead Unity
4	solar	bus 19 bus 28 bus 40	9.7 1.06 2.38	0.95 lead Unity Unity
5 (mix)	Dispatchable Wind solar	bus 40 bus 19 bus 40	0.82 3.3 4.2	0.95 lead 0.95 lead 0.95 lead

These results in (scenario 3 and 4) are reasonable because the sensitivity analysis shows thatbus 19 is less sensitive to the injection of real and reactive powercompared to bus 40. In addition, the voltage is more sensitive tothe change in reactive power than real power. As a result placinga DG unit operating in leading power factor is better in upperstream to avoid the violation of the voltage constraints.

In scenario 5 (Table III), all of the DG units are operatingat 0.95 leading power factor. The renewable DG units are sizedand placed in bus 19, while the dispatchable DG unit is sized andsitted in bus 40. In this scenario, the ratings of the DG units aresmaller compared to the other scenarios, because the dispatch-able DG units are operating at constant real and reactive power(their capacity factor equal 1), therefore it improves the voltagestability constantly during the year. Thus, the constant operation of the dispatchable DG unit is less dependent on renewableenergy DG units in improving the voltage stability margin, andhence their ratings are small.

VII. CONCLUSION

In this paper, a method of DG units allocation is proposed.This method targets utilizing the DG units to improve thevoltage stability margin. It considers the probabilistic nature ofboth loads and renewable DG generation. The load is modeledby the IEEE-RTS system. The data is used tomodel the solar irradiance and wind speed by Beta and Weibullprobability distribution functions, respectively. The candidatebuses for the DG units' installation are selected based on thesensitivity to the voltage. Simulation results indicate that DGsize and location can have positive impacts on the voltage stability margin. Therefore, an optimization method can be used todetermine the locations of the DG units, to achieve thetarget of improving the voltage stability margin. Simulation shows that placing and sizingDG units is affected by the operating condition of the DG units(unity power factor or between 0.95 lead or lag). When the DGunits operate at unity power factor, they arerecommended to beplaced in the most sensitive voltage buses in order to improvethe voltage stability margin with a condition of not violatingthe system voltage and current limits. However, if the utilityallows operating the DG units between 0.95 lead and 0.95 lag,the reactive power during leading power factor could improvethe voltage stability margin due to the moresensitivity between$\Delta V/\ \Delta Q$ than$\Delta V/\Delta P$. Therefore, theDG units with higherrating might be placed in upper stream of a radial distributionsystem in order to keep the system operating within the allowedlimits of voltage and currents.

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