Impact of Embedded Generation on Power Distribution System Voltage Collapse

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Abstract
The term "embedded generation"(EG) refers to electricity generation connected at distribution level rather than transmission level.
E.G. can reduce the effect of losses while providing reactive power and contingency reserves to the network.
It can also reduce the need for new transmission and distribution facilities consequently reducing overall costs.
A distribution system is the system of an overall power system which links the bulk system to the individual customers.
Voltage stability is an important performance index which defines the quality of supply.
This paper presents the impact of embedded generation (EG) on power distribution system voltage collapse.
ABUAD is considered as a case study in the research paper. The voltage stability indices (VSI) are calculated and assessed. The distribution network is reconfigured and the new values of VSI were computed to analyze the optimum configuration.
The result of the paper showed that after thee reconfiguration of the system network the maximum KW, KVAR and KVA connected loads on the four selected transformers have increased by 9.11%, 9.04% and 8.44% respectively.
The VSI for transformer T1 has increased from 0.0035 to 0.00362 while the VSI for transform T2 also decreased from 0.003845 to 0.0037 after the network reconfiguration. The VSI for transformer T3 and T4 remained constant even after the system network has been modified. The distribution system can be optimized for improved performance indices of which voltage stability is significant.
Keywords: Embedded Generation, Voltages Collapse, Stability Index, Distribution Networks, Reconfiguration, Improved Performance, Transformers.

1 .Introduction

The introduction of EGs can significantly impact the flow of power and voltage conditions at consumers and utility equipment.

The impact may either manifest themselves positively or negatively depending on the distribution operating characteristics and the EG itself (Billinton and Allan 1992).Embedded generation (EG) has the potential to promote the extensive use of renewable sources.

Voltage collapse, a form of voltage instability, commonly occurs as a result of reactive power deficiency. Unmitigated rotor angle instability can also result in voltage instability.

A power system undergoes voltage collapse if the post disturbance equilibrium voltage near load are below acceptable limits as a result of voltage instability (Billinton et al, 1990).A system experiences a state of voltage instability when there is a progressive or uncontrollable drop in voltage magnitude after a disturbance, increases in load demand or change in operating condition. The main factor, which causes these unacceptable voltage profiles, is the inability of the distribution system to meet the demand for reactive power(Endrenyi 1980)..The stability of a system of interconnected dynamic component is its ability to return to normal or stable operation after having been subjected to some forms of disturbances. The study of stability is one of the main concerns of the control engineers whose methods may be applied to electric power systems(Billinton and Garry 1993)

The voltage stability analysis process involves the transfer of Power from one region of a system to another and monitoring the effects of the system voltages. This type of analysis is referred to as a PV study. This is illustrated in Figure 1.

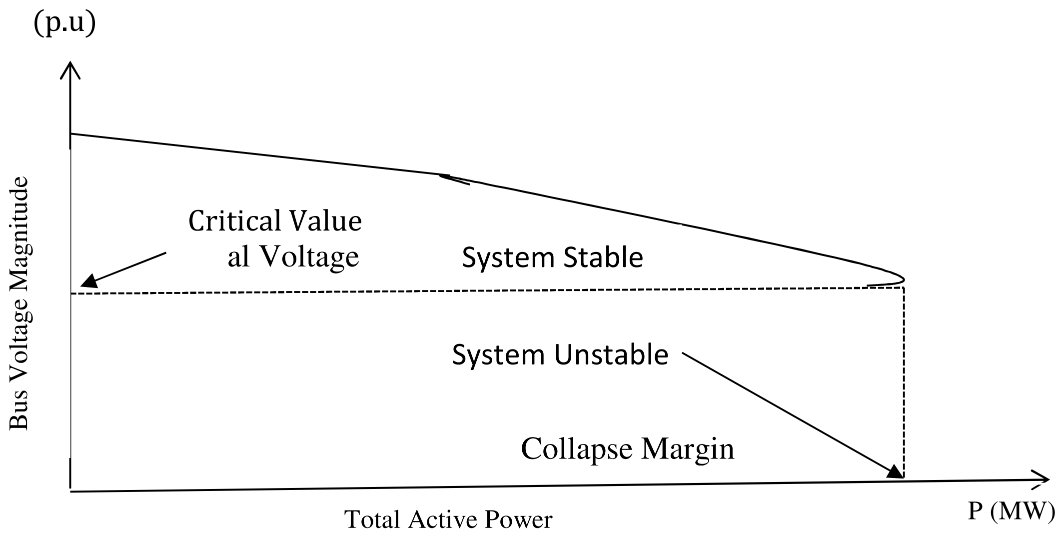

Figure 1: Typical Power-Voltage (PV) characteristics

1.1. Reactive Power Q and Voltage V Curve

Voltage stability depends on how the variations in Q and P affect the voltages at the load buses. The influence of reactive power characteristics of devices at the receiving end (loads or compensating devices) is more apparent in a QV relationship.

The sensitivity and variation of bus voltages with respect to reactive power injections or absorption Is shown in Figure 2.

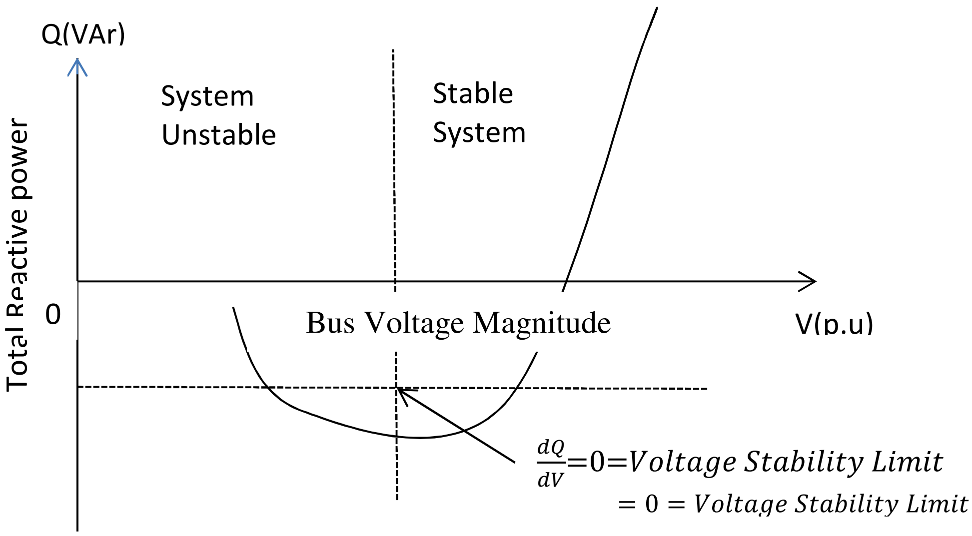

Figure 2: Typical Reactive Power-Voltage (QV) characteristic Curve

This point also defines the minimum reactive power requirement for a stable operation [3]. An increase in Q will result an increase in voltage during normal operating conditions. Hence, if the operating point is on the right side of the curve, the system is said to be stable.

Conversely, operating points in the left side of the graph are deemed to be unstable.

Voltage stability is generally characterized by loss of a stable operating point as well as by thee deterioration of voltage levels in and around the electrical centre of the region undergoing voltage collapse(Yifan, 1996)..

Voltage stability is commonly analyzed by employing two technique, namely time-domain (dynamic) simulation and steady-state analysis. Depending on the stability phenomenon or phenomena under investigation, one or both of these technique may be applied.

Voltage collapse may be total (blackout) or partial.

The voltage instability and collapse may occur in a time of fraction of a second.

In this case the term 'transient voltage stability' is used. Sometimes, it may take up to tens of minutes in which case the term 'long-term voltage stability' is used(Allan, et al 1991).

1.2 Factors Affecting Voltage Instability and Collapse

(i) The voltage collapse occurs invariable following a large disturbance or large load increase in a heavily stressed power system.
(ii) This results in an increased reactive power consumption and voltage drop.
(iii) The voltage drop causes initial load reduction triggering control mechanism for load restoration. It is the dynamics of these controls that often lead to voltage instability and collapse.

1.3 Timeframes in voltage stability studies

(i) Short-term
(ii) Mid-term
(iii) Long-term

1.3.1 Short-Term Timeframe

Short-term timeframe involves the time taken between the onset of a system disturbance to just prior to the activation of the automatic LTC. Rotor angle instability and voltage instability can occur within this timeframe. The following fast acting, automatically controlled power system equipment may be considered in assessing system performance within this timeframe (manjunath and Screedher 1998):

(i) Synchronous Condensers
(ii) Automatic switched dynamics
(iii) Induction motor dynamics
(iv) Static VAr Compensators
(v) Flexible AC Transmission System (FACTS) devices
(vi) Excitation system dynamics
(vii) Voltage-dependent loads

1.3.2 Mid-Term Timeframe

Mid-term timeframe refers to the time from the onset of the automatic LTC operation prior to the engagement of over-excitation Limiters (OEL). During this time, frequency and voltage stability may be of interest.

Long-Term Timeframe

Long-term timeframe refers to the time after OELs engage and includes manual operator-initiated actions. During this timeframe, longer-term dynamics come into play such as governor action and load-voltage and/or load-frequency characteristics in addition to operator-initiated manual system adjustments (Bian and Rastgoufard 1994, Yifan 1996).

2. Materials and method.

Afe Babalola University, Ado-Ekiti (ABUAD) Campus is a typical distribution system used as a case study in this research paper. The campus has varying loads at different periods of the day. The distribution system comprises of 11 KV in-coming feeders. The 11 kV 220V transformers are situated at various sites. The variation of loads at different transformers during various hours of the day is the main problem encountered in ABUAD. The main concentration of the load during the morning hour is at the campus building where large power is needed to supply the load demands of various classes, laboratories, library and offices e.t.c. During this period, the demand from various hostels is quite low.

During the evening hours, the maximum demand of power is from the quarters of staff and hostels. A continuous supply should be there to cater for the demands of power for lightning the bulbs and tube lights, computers and fans. The use of some equipment like heater, which consumes a lot of reactive power, caused a considerable drop in the supply voltage.

Procedural Steps in the Analysis

The following procedural steps were taken in the analysis:

I. Computation of the Voltage Stability Index (VSI) for the various buses.

The voltage stability has been defined as the ability of a system to maintain voltage at all parts of the system so that with the increase of load, both active and reactive power are controllable.

The formula used for calculation of VSI is:

$$VSI = 4[\left(X_{eq}P_{leq} - R_{eq}Q_{leq}\right)^2 + X_{eq}Q_{eq} + R_{eq}P_{leq}] \quad (1)$$

Where,

$$R_{eq} = \sum P_{loss}/\{(P_{leq} + \sum P_{loss})^2 + (Q_{leq} + \sum Q_{loss})^2\} \quad (2)$$

$$X_{eq} = \sum Q_{loss}/\{(P_{leq} + \sum P_{loss})^2 + (Q_{leq} + \sum Q_{loss})^2\} \quad (3)$$

Where P_{leq} and Q_{leq} are the total and reactive loads.

ii Reconfiguration of the loads of the transformer is done to get better VSI.

iii Selection of four transformers T1, T2, T3 and T4 with ratings of 500KVA, 500KVA, 500KVA and 300KVA respectively.

iv Determination of the loads supplied by each transformer to ascertain the maximum connected loads in KW, KVAR and KVA rating.

v Reconfiguration or modification of the simple line diagram of ABUAD distribution system to obtain calculated data for the new loads.

vi Calculation of the VSI for original and modified configuration.

3. Discussion of Results

Figure 1 shows the ABUAD Campus distribution system before the reconfiguration while Figure 2 illustrates ABUAD Campus distribution system after the reconfiguration.

Figure 3 shows the graphical relationship between the original maximum connected loads and transformers for ABUAD campus distribution system.

The original maximum KW, KVAR and KVA loads for the first transformer T1 (500KVA) are 1416.9KW, 1145.62KVAR and 1781.98KVA respectively. This transformer is connected to the campus College of Engineering with maximum connected loads of 800.75KW, 623.5KVAR and 1013.84KVA. Water supply is also fed by this transformer with maximum connected loads of 163.25KW, 118.47KVAR and 193.53KVA. Four male hostels A, B, C and D were also attached to this transformer with maximum connected loads of 263KW, 190KVAR and 314.36KVA. The Campus Canteen and Quarters (1 and 2) were also fed by this 500KVA transformer. The maximum connected loads for the Canteen and Quarters (1 and 2) are 110KW, 85KVAR, 115KVA and 79.9KW, 128.65KVAR, 145.26KVA respectively.

Transformer T2 (500KVA) was connected to feed the College of Law with maximum connected loads of 700.60KW, 523.38KVAR and 927.25KVA while Hostels E.F and G with maximum loads of 180.4KW, 273.4KVAR and 323.7KVA were also connected to this transformer.

This transformer also fed the inner quarters with maximum connected loads of 623KW, 445.32KVAR and 715.46KVA. Thus, this 500KVA transformer had total maximum loads of 1504KW, 124.02KVAR and 1966.41KVA connected to it.

Transformer 3 (500KVA) fed the administrative building of the campus with maximum connected loads of 452.64KW, 280.18KVAR and 545.36KVA.

Hostels H and I were also connected to the transformer with maximum loads of 493.72KW, 374.52KVAR and 615.24KVA. Sports complex and Quarter's canteen were also connected to the transformer with maximum loads of 19KW, 8.5KVAR, 13.6KVA and 12KW, 8.9KVAR, 14.5 KVA respectively bringing the total maximum connected load on this transformer to 977.36KW, 672.1KVAR and 1188.7KVA.

The post-graduate school and the Health Centre of the campus were connected to transformer T4 (300KVA) in order to avoid over loading any of the transformers T1, T2 or T3.

The maximum loads connected to this transformer T4 (300KVA) are 146.32KW, 93.25KVAR, 173.47KVA and 153.47KW, 95.38KVAR, 184.92KVA respectively.

The two guest houses A and B of the campus were connected to this 300KVA transformer with maximum connected loads of 148.32KW, 90.62KVAR, 176.23KA and 142.58KW, 85.93KVAR, 165.73KVA respectively, thus, bringing the total maximum loads connected to this transformer to be 590.69KW, 365.181KVAR and 700.55KVA.

Figure 4 shows the relationship between the calculated maximum connected load and the transformers when the single line diagram of the campus is modified.

The maximum connected loads for the first transformer T1 (500KVA) were calculated to be 1465KW, 1187.92KVAR and 1875KVA which shows an increase of 48.1KW from the original KW value of 1416.9KW and a KVAR difference of 4.23KVAR as against the original KVAR value of 1145.62KVAR. The KVA value has also increased from 1781.98KVA in the original situation to 1875KVA in the calculated case. Thus the KVA positive difference is 93.02KVA. The calculated KW, KVAR and KVA data for the second transformer T2 (500KVA) are 1498.6KW, 1232.14KVAR and 1887KVA which represents a difference of 5.4KW, 9.88KVAR and 79.41KVA after the reconfiguration.

The third transformer T3 (500KVA) had maximum connected positive load difference of 167.88KW, 160.36KVAR and 156.3KVA which represent, about 17.2%, 23.9% and 13.1% respectively of the KW, KVAR and KVA rating.

The calculated data for transformer T4 (300KVA) after reconfiguration were 789.21KW, 515KVAR and 920KVA which represent positive difference of 198.52KW 149.82KVAR and 219.65KVA as compared to the original maximum connected loads of 590.69KW, 365.18KVAR and 700.35KVA.

Figure 5 shows the relationship between the maximum connected loads (original and final) and transformers while the relationship between these differences and the transformers are also shown in Figure 6.

The values of the VSI for both the original and modified configurations are shown in Figure 7. it is observed that as the load on transformer T1 decreases, its VSI increases from 0.0035 to 0.00362 and that of transformer T2 decreases from 0.003845 to 0.0037. A slight improvement in the VSI of the overall system is observed.

As the load on transformer T3 increases from 977.36KW, 672.1KVAR and 1188.7KVA to 1145.24KW, 832.46KVAR and 1345KVA, the VSI remains constant even after the modification of the system configuration.

The VSI also remained constant after modification for transformer T4 when the load connected on it increased from 590.69KW, 365.18KVAR and 700.35KVA to 789.21KW,, 515KVAR and 920KVA, thus representing percentage increase of 33.61%, 41.02% and 31.36% in the original KW, KVAR and KVA rating. The results of the VSI for the original and modified systems show that there is an appreciable level of improvement in the voltage stability.

4. Conclusion

The total original connected loads on the four transformer T1, T2, T3 and T4 were 4488.93KW, 3424.92KVAR and 5682.84KVA while that of final connected loads obtained from calculation from the four transformer were 4498.05KW 3767.52KVAR and 6027KVA representing total percentage increase of 9.11%, 9.04% and 8.44% in the KW. KVAR and KVA rating.

The VSI for transformer T1 has increased from 0.0035 to 0.00362 while the VSI for transformer T2 has decreased appreciably from 0.003845 to 0.0037.

The VSI for transformer T3 and T4 remained the same after the modification. Thus before and after modification of the system configuration, the VSI remained constant at 0.00457 and 0.0055 respectively. Thus, for the four transformers combined, the VSI has increased from 0.017415 to 0.05852 after the modification of the system configuration. In this case, optimal configuration of the distribution system can be obtained with acceptable values of VSI. The use of various optimization techniques such as Genetic algorithm and Tabu search can be used to achieve the optimization. ABUAD distribution system can be optimized for enhanced performance indices of which voltage stability is very paramount.

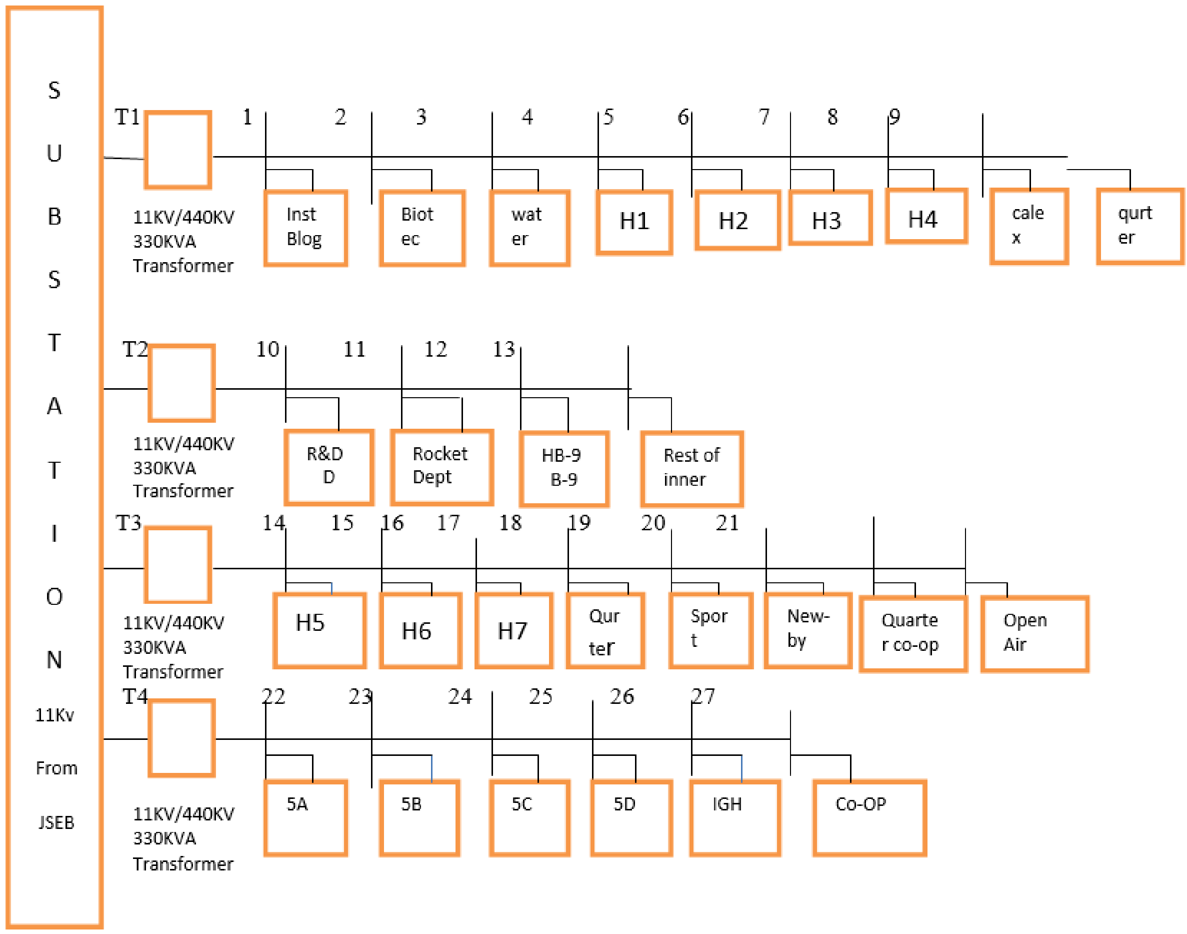

Figure 3: Single line diagram showing ABUAD Campus distribution system.

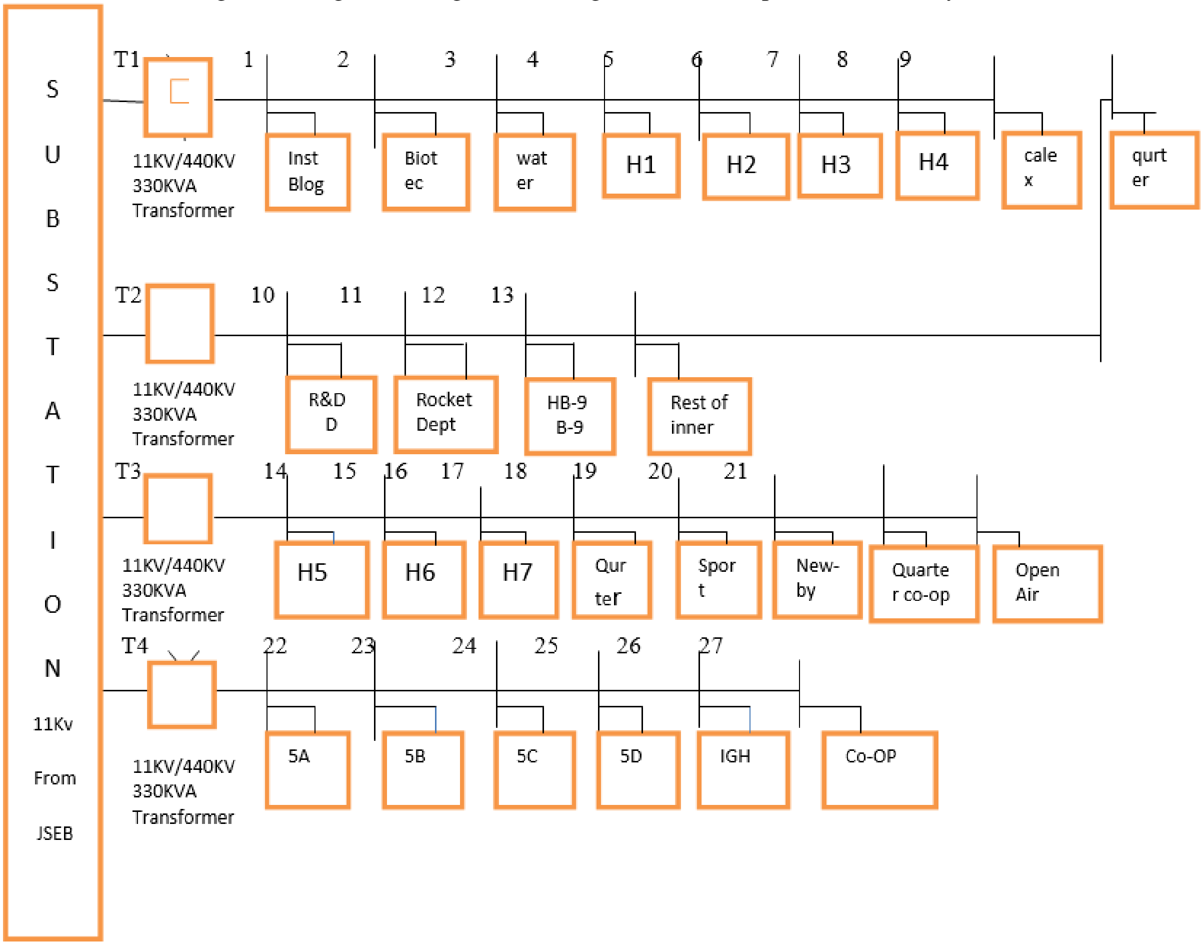

Figure 4: Modification of the ABUAD Campus distribution system

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