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IMPACT OF PHOTOVOLTAIC DISTRIBUTED GENERATION ON UNBALANCE PHENOMENON IN DISTRIBUTION FEEDER

J. P. Sharma*[1], H. R. Kamath[2]

[1]Electrical Engineering Department, JK Lakshmipat University, Jaipur, India,
[2]Instrumentation & Control Engineering Department, Manipal Institute of Technology, India,

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ABSTRACT

In a smart grid environment, voltage sensitive composite load characteristics, poor voltage profile and rapid integration of distributed generation (DG) are imperative to compute reactive power status at the point of coupling (PCC) during each iteration of load flow computation. In this work, a fuzzy expert system based photo voltaic DG placement has been utilized to evaluate stochastic unbalance phenomenon for a modified IEEE 37 node test feeder. Key performance parameters are evaluated for six different DG operational modes and compared with results obtained in the base case. By investigation of obtained stochastic unbalance results for different six PV DG operational modes, it has been observed that DG operational mode at 0.95 lead power factor is more suitable than other ways for improving unbalance phenomenon.

Keywords: unbalance phenomenon; distributed generation; stochastic feeder performance.

Author Correspondence, e-mail: jpsharma.cseb@gmail.com

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1. INTRODUCTION

As the unbalance phenomenon of a distribution system restricted the progressions to proficiency upgrades, cost diminishes, and power quality improvements. The unbalance phenomenon caused due to structural and operational aspects, which deteriorate qualitative and secure power supply at a reasonable cost to consumers. An unbalance phenomenon deteriorates the performance improvement initiatives for an unbalance distribution system. Thus, a more thorough understanding needed to benchmark the factors affecting unbalance phenomenon for a distribution feeder. The factor affecting the unbalance in current, voltage and power are utilized to minimize unbalance in electrical distribution systems. The common measures against unbalance phenomenon are load balancing, conservation voltage reduction, up gradation of an existing system, reactive power compensation, and distributed generation integration. The global warming concerns have stressed utilities to integrate distributed generation (DG) units with low and medium voltage network. The distributed generators (DG) unit integration to a practical feeder may be operated as either PQ or PV DG models. The feeder integration of PV model may have issues with voltage regulation, compromised power quality, and malfunctioning of protective equipment. Thus, an efficient load flow algorithm needed to integrate PV DG model for improving unbalance behavior and malfunctioning of the equipment's.

The impact of DG integration to an unbalance distribution system has been investigated on various aspects such as static voltage stability, power loss, fault current, and voltage [1]. An effective approach proposed to handle PV distributed generation nodes for radial and weakly meshed transmission and distribution networks [2]. A sensitivity impedance matrix based load flow demonstrated to IEEE 13 node test feeder [3]. The impact of electric vehicles, photovoltaic and wind units' integration on voltage unbalance carried out to a practical distribution system, which is located in Thailand [4]. Unbalance loading and inherent characteristics of a practical feeder restricted the optimal utilization of available resources. Practical consequences of unbalance phenomenon evaluated in terms of feeder loss and transformer loading, which is further examined with experimental work [5].The impact of a stochastic model of synchronous generators and PV system on IEEE 13 test feeder investigated in terms of voltage unbalance and feeder loading [6]. Stochastic performance indices such “substation reserve capacity, voltage unbalance factor, feeder power loss to load ratio, branch loading, voltage deviation, and power factor” were developed for the highly unbalancing radial feeder [7]. A fuzzy system based DG integration approach utilized to a practical feeder by considering deciding parameters such as “substation reserve capacity, feeder power loss to load ratio, voltage unbalances, apparent power imbalances, and survivability indices”. The impact of constant power DG integration on performance indices has been demonstrated under at different power factor in stochastic environment [8].

This paper is an extension of work reported in just above reference and a modified IEEE 37 feeder is integrated to a constant PV DG with six different operational power factor cases during 35 to 73 period of metering time interval. The impact of this integration studied on unbalance phenomenon in terms of substation reserve capacity, voltage unbalances, voltage deviation and apparent power imbalance.

2. OVERVIEW OF TEST SYSTEM

2.1. Unbalance Phenomenon

Unbalance phenomenon caused by appliances of commercial and industrial consumers, which reflects non-symmetrical voltages, current, and power in distribution systems. In a competitive environment, a qualitative and reliable power supply is a paramount aspect. The common factors responsible for the imbalance in a distribution system can be quantified in relatively by utilizing indices as mentioned below [7].

- **Apparent Power Unbalance Indice (APBI):**

$$\mathrm{APBI}^{h}_{abc} = \sqrt{\frac{1}{3}\left(\sum_{k=1}^{NL}\left|S^{h}_{abc}(k) - \mathrm{AVS}^{h}(k)\right|^{2}\right)} \tag{1}$$

$$\mathrm{AVS}^{h} = \frac{1}{3}\left[S^{h}_{a}(k) + S^{h}_{b}(k) + S^{h}_{c}(k)\right]$$

- **Substation Reserve Capacity Indice (SRCI):**

$$\mathrm{SCRI}^{h} = 1 - \frac{\left|S^{h}_{a01}(k)\right| + \left|S^{h}_{b01}(k)\right| - \left|S^{h}_{c01}(k)\right|}{S^{\mathrm{Substation}}} \tag{2}$$

- **Voltage Unbalance Factor (VUF):**

$$Tdo^{h}_{abc} = \sqrt{\frac{1}{N}\left(\sum_{k=1}^{N}\left|\frac{V^{h}_{oabc}(k)}{V^{h}_{+abc}(k)}\right|^{2}\right)}, Td2^{h}_{abc} = \sqrt{\frac{1}{N}\left(\sum_{k=1}^{N}\left|\frac{V^{h}_{-abc}(k)}{V^{h}_{+abc}(k)}\right|^{2}\right)} \quad (3)$$

$$Tdt^{h}_{abc} = Tdo^{h}_{abc} + Td2^{h}_{abc}$$

- **Voltage Deviation Indice (VDI):**

$$VDI^{h}_{abc} = \max\left\{\frac{\left|1 - V^{h}_{abc}(k)\right|}{\Delta VR}\right\}_{k=1}^{N} \quad (4)$$

2.2. Test system and load flow computation

The modified IEEE 37 distribution test feeder with delta connected load buses having a mix of industrial, residential and commercial consumers. A typical normalized load pattern is utilized for different consumers as shown in Fig.1. The load model for each type of category consumers described as a mix of constant power (PQ), constant impedance (Z) and constant current (I) models. Each feeder component is modeled using ABCD parameters. The metering time interval for a whole day is taken as 15 minutes [7]. The PV distributed generation is connected to node 734 as shown in Fig. 2 [8].

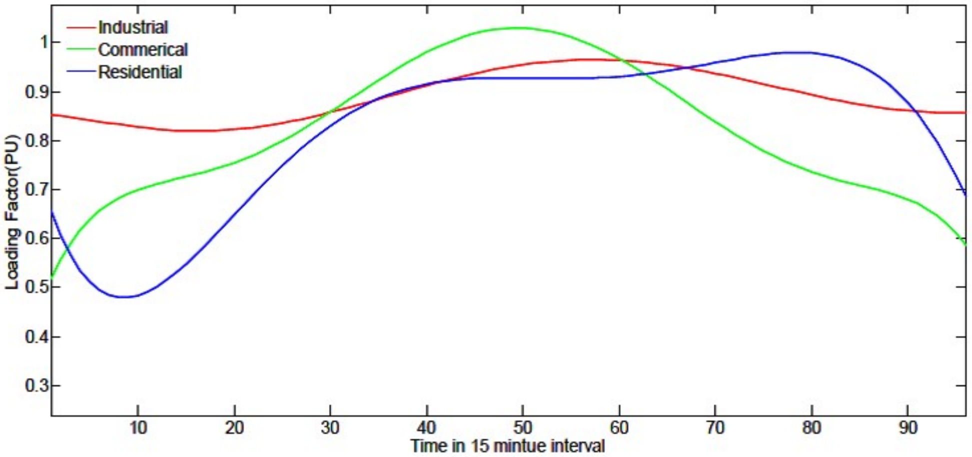

Fig.1. Typical daily load profile for consumers

As far as operation and planning concerned, stochastic behavior investigation of DG integrated distribution feeder is a challenging aspect. A fuzzy expert system is utilized to determine optimal sizing and location of DG for evaluating unbalance phenomenon as shown in Fig.3 [8]. The load computation work is subjected to constraints such as connectivity of all nodes and radial structure of feeder.

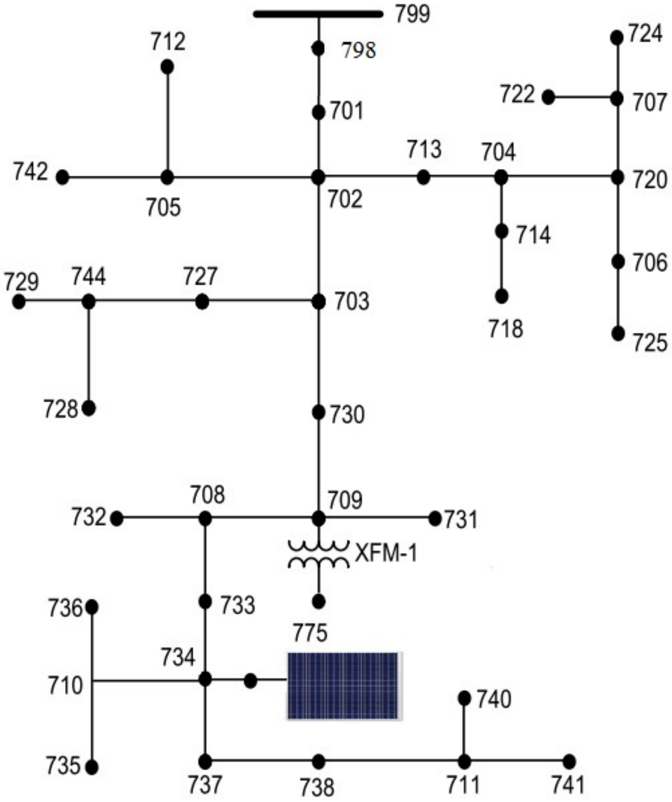

Fig.2. Modified test feeder

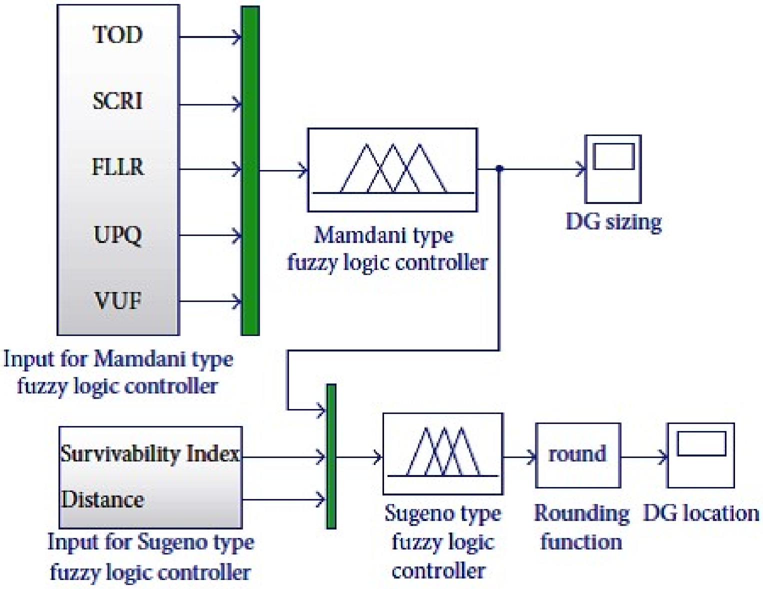

Fig.3. Fuzzy expert system

Voltage, active and reactive power injection by DG at the point of coupling (PCC) continually fed to power electronics interface devices to govern the operational mode of DG. In PQ mode injection parameters are active power and voltage at PCC, while in PV mode these parameters are active and reactive power. The computational work is illustrated in Fig. 4.

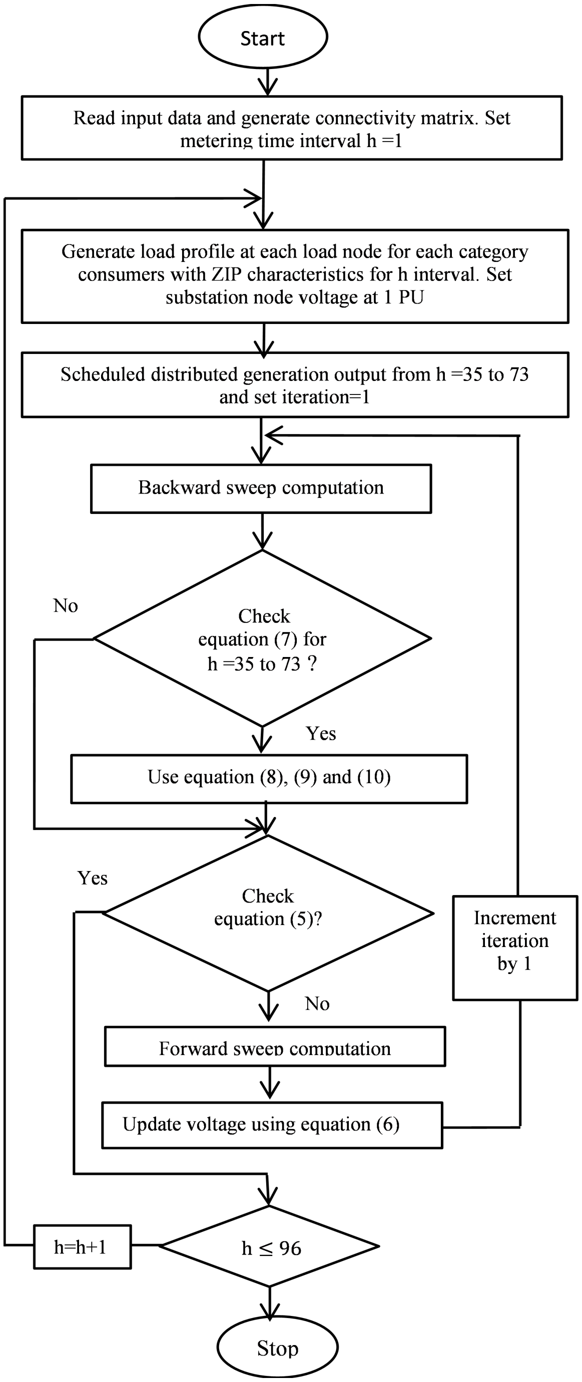

Fig.4. Flow chart for load flow computation

A procedure to handle both PV and PQ DG model in load flow computation broadly discussed [9].In this paper, PV DG model at different power factor scenarios are utilized, which required an efficient load flow algorithm to cater some additional process as mentioned below.

- The substation node voltage is computed as per constraint (5). In case of dissatisfaction of above the constraint, equation (6) utilized for updating the voltage of each end node k. The mismatch in voltage at PV node is checked by equation (7).

If equation (7) doesn't satisfied, then reactive power injection required to maintain PV voltage profile at different operational power factor of DG is computed with the help equation (8), (9) and (10). A list of nomenclatures is shown in appendix.

$$|[E_{abc}]_{itr+1} - [E_{abc}]_{itr}| \leq 1e^{-5} \tag{5}$$

$$[V_{abc}(k)]_{itr+1} = [V_{abc}(k)]_{itr} + ([V_{abc}(k)]_{itr} * [I_{abc}(k)]_{itr} - [S_{abc}(k)]_{itr}) * \left(\frac{VBASE}{PBASE}\right) * [V_{abc}(k) - V_{nominal}(k)\ ]_{itr} \tag{6}$$

$$|VPV_{abc}|_{itr} - |VPV_{abc}|_{specified} \leq 1e^{-5} \tag{7}$$

$$imag[(IPV_{abc})_{itr}] = imag[(IPV_{abc})_{itr-1}] + imag[(IPV_{abc})_{itr} - (IPV_{abc})_{itr-1}] \tag{8}$$

$$real[(IPV_{abc})_{itr}] = -\,imag[(IPV_{abc})_{itr}] * \left(\frac{imag(VPV_{abc})_{itr}}{real(VPV_{abc})_{itr}}\right) \tag{9}$$

$$(QPV_{abc})_{itr} = (QPV_{abc})_{itr-1} + imag[(IPV_{abc})_{itr} - (IPV_{abc})_{itr-1}] + \left[\frac{abs(VPV_{abc})_{itr}{}^{2}}{real(VPV_{abc})_{itr}}\right] \tag{10}$$

3. SIMULATION RESULTS AND ANALYSIS

A 24-hour load flow for each 15 minutes metering interval computed in MATLAB with varying voltage sensitive load demands for a modified IEEE 37 node test feeder [7]. A photovoltaic DG of 440KW per phase capacity integrated at node 734, and to keep different constant power factor, the required PV DG reactive power of the DG is computed by equation (10) for each iteration.

In the base case, the unbalance phenomenon indices are computed without any DG integration for the whole day. The PV distributed generation integrated for the period of 35 to 73 metering time interval to investigate the impact on voltage and apparent power with different DG operational power as shown below Fig. 5 to 10.

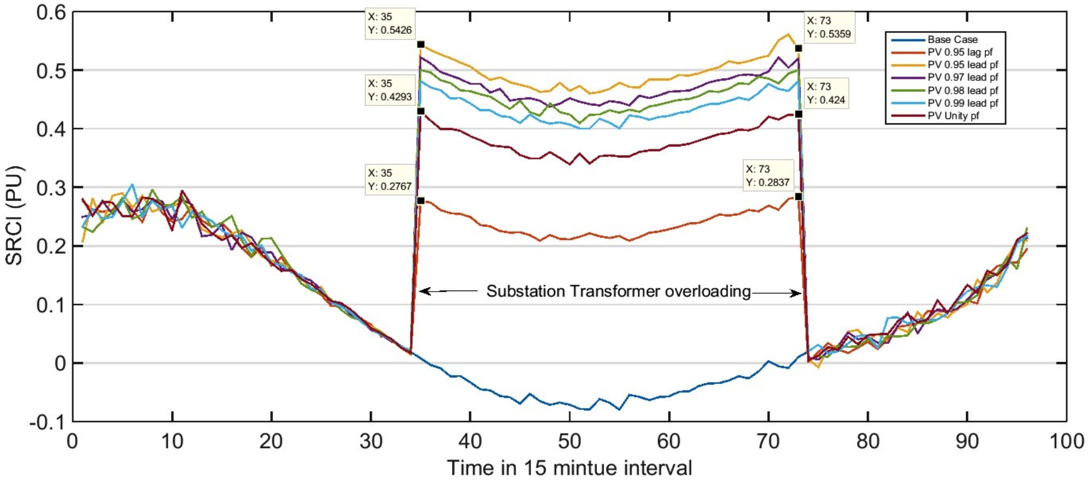

Fig.5. Substation reserve capacity indice

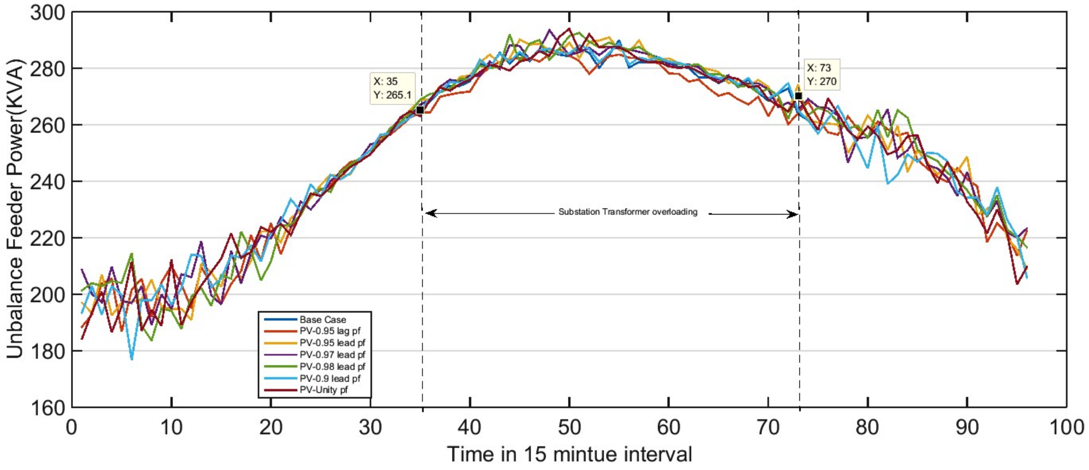

Fig.6. Apparent powers unbalance indice

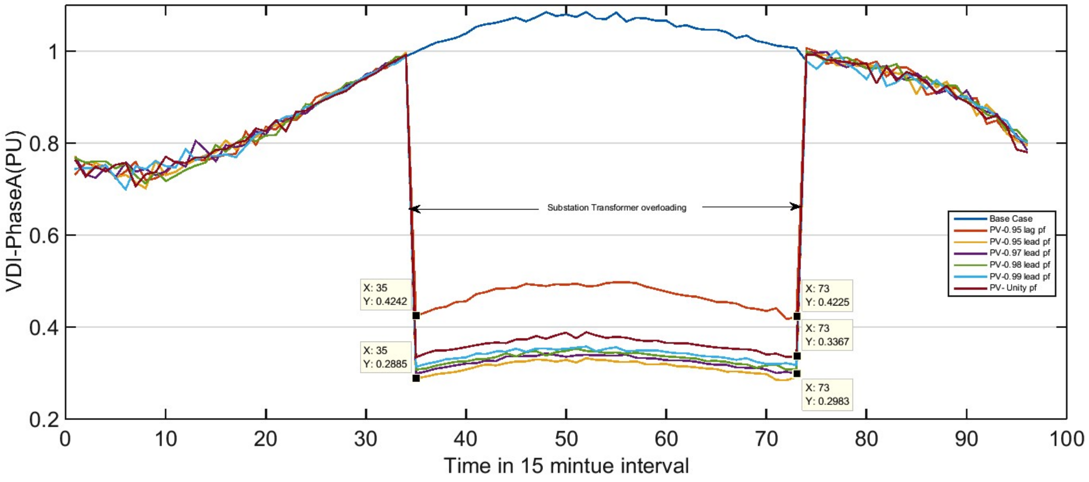

Fig.7. Maximum phase A voltage deviation

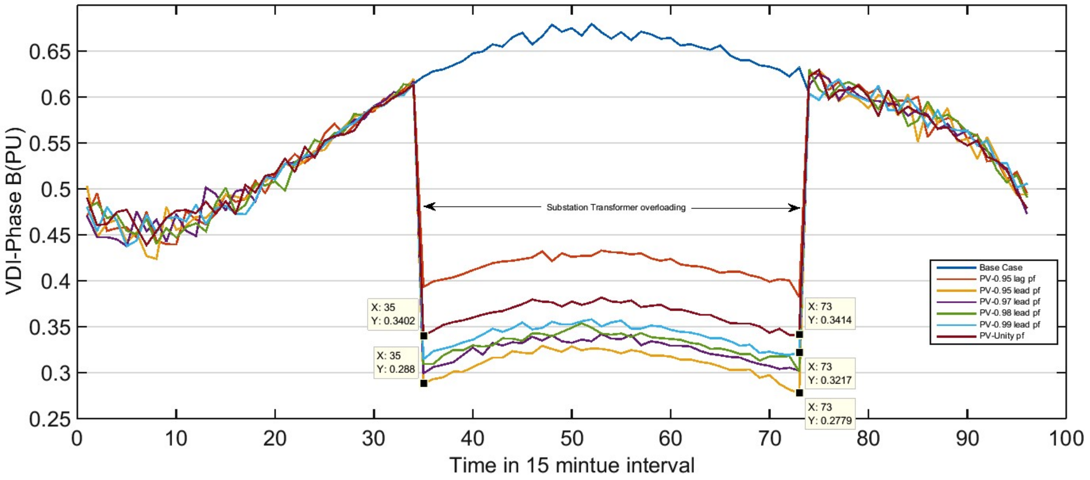

Fig.8. Maximum phase B voltage deviation

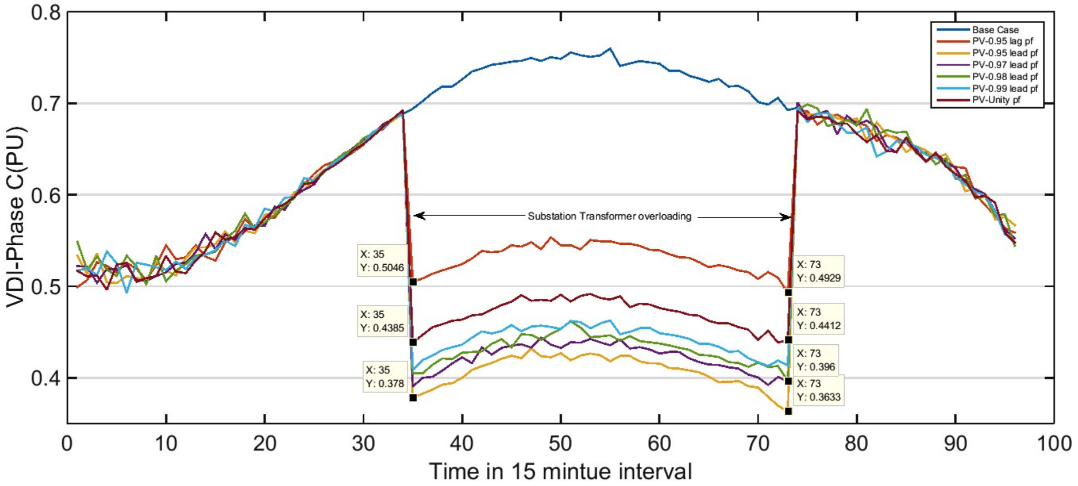

Fig.9. Maximum phase C voltage deviation

The substation reserve capacity and apparent powers unbalance indices of a test system as shown in Fig. 5 and Fig. 6 respectively. It has been observed that in 0.95 lead power factors mode of operation has supplied greatest active power by PV DG as shown in Fig. 5. It is also notable from Fig. 6 that there is not any significant change in feeder apparent power for all operational modes.

As far as the voltage deviation is concerned for a test system, 0.95 lead power factor mode of PV DG operation holds the least value for all three phases as shown in Fig. 7, Fig. 8, and Fig. 9 respectively. Voltage unbalances factor found maximum for 0.95 lead power factor mode of PV DG operation case as shown in Fig. 10.

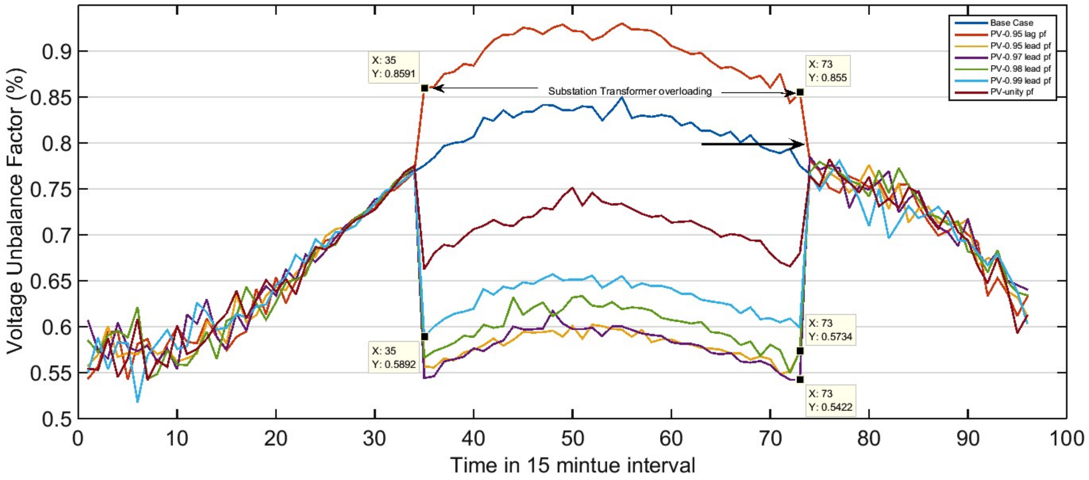

Fig.10. Voltage unbalance factor

The intersecting observation is that 0.95 lead operational power factor cases for PV DG have highest improvement for discussed indices for all phases during the integration period; while 0.95 lag power factor case of PV DG operation has lowest improvement for same.

4. CONCLUSION

This paper has investigated the impact of PV DG system at different operational power factor on unbalancing phenomenon for highly unbalancing IEEE 37 node test feeder having stochastic voltage sensitive load models. A fuzzy expert system is utilized for PV DG system integration on node 734. Moreover, PV node handling capability of proposed load flow for a practical feeder with good convergence criteria. Indices have been utilized to assess the feeder unbalance phenomenon in terms of substation reserve capacity, voltage unbalances, voltage deviation and apparent power imbalance. Results obtained with PV DG system are compared with results obtained in the base case. The power factor control strategy was found to be more effective to reduce unbalance phenomenon in the feeder may be beneficial for supporting PV inverters in reactive power support.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

[1.] Roy N. K., Pota H. R., and Mahmud M. A. DG integration issues in unbalanced multi-phase distribution networks. 2016 Australasian Universities Power Engineering Conference (AUPEC), Brisbane, QLD, 2016, 1-5.doi: 10.1109/AUPEC.2016.7749381

[2.] Rajicic D., and Dimitrovski A. A new method for handling PV nodes in backward/forward power flow for radial and weakly meshed networks. IEEE Porto Power Tech Proceedings (Cat. No.01EX502), Porto, 2001, 3 doi: 10.1109 /PTC.2001.964896

[3.] Maya K.N. and Jasmin E. A. A Three Phase Power Flow Algorithm for Distribution Network Incorporating the Impact of Distributed Generation Models. Procedia Technology, 2015, 21, 326-331.doi:https://doi.org/10.1016/j.protcy.2015.10.040.

[4.] Panich S., and Singh J.G.. Impact of plug-in electric vehicles on voltage unbalance in distribution systems. International Journal of Engineering, Science and Technology, 2015, 7(3), 76-93.doi: http://dx.doi.org/10.4314/ijest.v7i3.10S.

[5.] Bina T.M., and Kashefi A.Three-phase unbalance of distribution systems: Complementary analysis and experimental case study. Electrical Power and Energy Systems, 2010, 33,817–826. doi:10.1016 /j.ijepes.2010.12.003

[6.] Emmanuel M., and Rayudu R. Equipment loading and voltage unbalance in the distribution network with distributed PVs. 2016 IEEE Innovative Smart Grid Technologies-Asia (ISGT-Asia), Melbourne, VIC, 2016; 9-14.doi: 10.1109/ISGT –Asia.2016.7796353

[7.] Sharma J.P. , and Kamath H. R. Fuzzy Logic Controller Based Distributed Generation Integration Strategy for Stochastic Performance Improvement, .Advances in Electrical Engineering,vol.2016, 1-13,(Article-ID9760538).doi: http://dx.doi.org/10.1155/20 16 / 9760538.

[8.] Sharma, J.P., and Kamath, H. Performance Analysis of Unbalance Radial Feeder with Time Varying Composite Load. Journal of Power and Energy Engineering, 2015, 3, 56-70. doi: 10.4236/jpee.2015.35005.

[9.] Moghaddas-Tafreshi S. M., and Mashhour E. (2009).Distributed generation modelling for power flow studies and a three-phase unbalanced power flow solution for radial distribution systems considering distributed generation. Electric Power Systems Research,2009,79(4),680-86.doi:https://doi.org/10.1016/j.epsr.2008.10.003

[10.] Sharma, J.P., and Kamath. A Framework for Stochastic Performance Improvement of an Unbalance Radial Feeder. PhD dissertation [Submitted], Mewar University, Chittorgarh, India, 2016.

Nomenclature

Table 1. List of symbol

Symbol	Description
h, r_t	15 minutes characteristics time interval, Turn ratio of transformer
N, NL	Total node, total line Segment
$S^h_{abc}(k)$, $AVS^h(k)$	Three phase and average apparent power to node k
$S^h_a(k), S^h_b(k), S^h_c(k)$	Phase outgoing power from node k during h
$V^h_{+abc}(k)$, $V^h_{-abc}(k), V^h_{0abc}(k)$	Positive, negative and zero sequence voltage at bus k during h
$Tdt^h_{abc}, S^{substation}$	Voltage unbalance factor, MVA capacity of substation transformer
$S^h_{a01}(k), S^h_{b01}(k), S^h_{c01}(k)$	Phase wise apparent power outgoing power from substation during h
ΔVR	Transformer branch, Voltage regulation (5%)
$V_{abc}(k)$, $I_{abc}(k)$	Phase voltage and current at node k
$VBASE, PBASE$	Base voltage and apparent power quantity
$V_{nominal}(k)$,	Nominal voltage at node k
$Tdt^h_{abc}, S^{substation}$	Voltage unbalance factor, MVA capacity of substation transformer
$(VPV_{abc})_{itr}$, $(IPV_{abc})_{itr}$,	Voltage and current injection by distributed generation integration node during iteration itr
$(QPV_{abc})_{itr}$,	Reactive power injection by distributed generation integration node during iteration itr

$(QPV_{abc})_{itr'}$	Reactive power injection by distributed generation integration node during iteration itr

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