Stochastic Power Flow Analysis of Unbalanced Distribution System based on cluster of SWTG-SPV

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Abstract— **This paper presents stochastic 3-ϕ power flow analysis of real-time unbalanced distribution system based on the aggregated and clustered model of Small Wind Turbine Generator (SWTG) and Solar Photo Voltaic (SPV) using OpenDSS. Single value decomposition based allocation and probabilistic approach of power-generation balance in every bus is modelled. 15 mins interval of wind velocity, solar irradiance and load data of Basaveshwar Engineering College (A), Bagalkot (BEC) profiles are recorded from Distribution Automation SCADA research laboratory for preparation of loadshapes. The proposed method is tested and validated on IEEE 15 and Europe LV Networks. Results for the studied High & Low Voltage (HV/LV) system indicate that buses with clustered (Distributed Energy Resources (DERs) have greater impact on voltage profile and thermal ampacity.**

Keywords—fixed-point iteration, monte-carlo simulation, single value decomposition.

I. Introduction

Power flow analysis is an essential tool for future planning, operation and maintenance of distribution system to make future μ-Grid. Uncertainty of intermittent nature of wind velocity, solar irradiance and dynamic loads are needed to be assessed. These uncertainties cannot be confidentially assessed unless the outcome of a study has an acceptable level of statistical significance. Indeed, many researchers depict the probabilistic analysis and impact assessment of DERs in LV system by the monte-carlo method with a large number of simulations [1]. Investigations are carried out on the effects of variable DERs on large rated distribution system mainly European grids/IEEE standard systems[2]. Further, joint correlation of wind farm, solar photovoltaic and bus loads in the distribution system helps to find the behavior of combined cumulants[3][4]. However, these techniques addresses the technical issues related to feeder levels and data clusters which are limited to only state of the DERs. In real-time secondary distribution system, voltage and current phasors are always unbalanced due to mixed type of loads. In this connection, techniques mentioned in above literatures are not suitable for secondary distribution because of productive current injection at LV level buses. Therefore, to achieve risk assessment of DERs in secondary distribution there is a need of stochastic analysis in mixed feeder levels, complex ZIP load and combined DERs. In this paper, probabilistic impact of Small Wind Turbine Generator (SWTG), rooftop Solar Photovoltaic (SPV) and 3-ϕ 4-wire load in distribution system are computed by fixed point iterative technique using OpenDSS. New approach for numbering the nodes/buses, clustering the SWTG-SPV based on the probabilistic generation-load balance by singular value decomposition are carried out. DERs and bus loads are modelled using the standard normal distribution function with real-time data. Proposed technique is tested on BEC 15[5], IEEE 15 bus distribution system and Europe LV network.

II. Single Value Decomposition (SVM) based Clustering and Aggregated Model of SWTG and SPV in the Distribution System

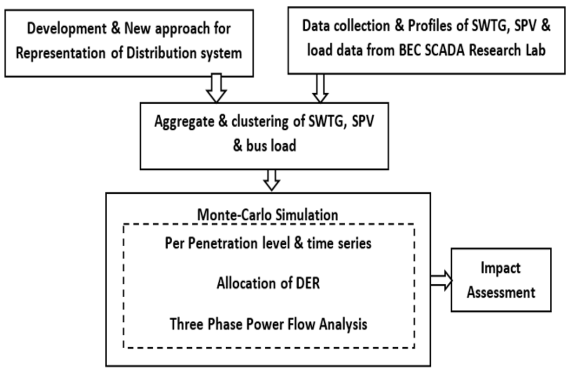

Fig. 1. Functional schematic diagram

The functional block diagram of the proposed method is shown in Fig.1. New approach and network modelling for representation of distribution system buses based on predecessor and successor method. SWTG and SPV are cluster and allocation based on the probability of load – generation balance in the real distribution system. Further, developed the aggregated model of combine SWT, SPV and bus loads using the Gaussian distribution method. SWTG & SPV is modelled based on uncertainty and as shown in eq. (1) & (2) [3]

$$P_{SWTG} = P_R \int_{V1}^{V_R} (a_1V^3 + a_2V^2 + a_3V^3 + a_4)\frac{k}{c}(\frac{v}{c})^{k-1} e^{-\left(\frac{v}{c}\right)^k} dv + P_R \int_{V_R}^{V_0} \frac{k}{c}(\frac{v}{c})^{k-1} e^{-\left(\frac{v}{c}\right)^k} dv \quad (1)$$

$$P_{SPV} = E\eta^{PV} S^{PV} \times \frac{1}{\sqrt{2\pi}\sigma_E} e^{(E^2/2\sigma_E{}^2)} \quad (2)$$

Similarly, Bus load also modelled is shown in Eq. (3)

$$P_L = \frac{1}{\sqrt{2\pi}\sigma_{L,i}} e^{\left[\frac{(d_{L,i}{}^{\alpha} - \mu_{L,i}{}^{\alpha})^2}{2(\mu_{L,i}{}^{\alpha})}\right]} \times \left(\alpha_0 + \alpha_1 \left| \frac{V_a}{V_0} \right| + \alpha_2 \left| \frac{V_a}{V_0} \right|^2 \right) P_0 \quad (3)$$

Power injection from SWTG and SPV are clustered at each bus in real distribution system. Clustering based on the Singular Value Decomposition (SVD) where classification and allocation of the SWTG and SPV according to the generation-load balance, and geographical location, described as

$$\left[U_{ij}{}^{\alpha}, V_{ij}{}^{\alpha} \right] = svd\left(A_{ij} \right) \quad (4)$$

Where, $U_{ij}{}^{\alpha}$ is the generation-load balance and $V_{ij}{}^{\alpha}$ is a geographical location factor. Fig.2 depicts the cluster model of SWTG-SPV. The current injection at each bus based on the aggregated and cluster model in practical distribution system is described as

$$\begin{bmatrix} Ia_{mn}{}^{r} \\ Ib_{mn}{}^{r} \\ Ic_{mn}{}^{r} \end{bmatrix} = \begin{bmatrix} Ia_{n}{}^{r} \\ Ib_{n}{}^{r} \\ Ic_{n}{}^{r} \end{bmatrix} + \begin{matrix} \sum all\ \ the\ \ I\ of\ branches\ \ \ from\ \ bus\ \ n\ \ \&\ \ phase\ \ a \\ \sum all\ \ the\ \ I\ of\ branches\ \ \ from\ \ bus\ \ n\ \ \&\ \ phase\ \ b \\ \sum all\ \ the\ \ I\ of\ branches\ \ \ from\ \ bus\ \ n\ \ \&\ \ phase\ \ c \end{matrix} \quad (5)$$

Voltage at each of the buses described as

$$\begin{bmatrix} Va_{mn}{}^{r} \\ Vb_{mn}{}^{r} \\ Vc_{mn}{}^{r} \end{bmatrix} = \begin{bmatrix} Va_{n}{}^{r} \\ Vb_{n}{}^{r} \\ Vc_{n}{}^{r} \end{bmatrix} - \begin{bmatrix} Z_{mn}{}^{aa} & Z_{mn}{}^{ab} & Z_{mn}{}^{ac} \\ Z_{mn}{}^{ba} & Z_{mn}{}^{bb} & Z_{mn}{}^{bc} \\ Z_{mn}{}^{ca} & Z_{mn}{}^{cb} & Z_{mn}{}^{cc} \end{bmatrix} \begin{bmatrix} Ia_{mn}{}^{r} \\ Ib_{mn}{}^{r} \\ Ic_{mn}{}^{r} \end{bmatrix} \quad (6)$$

Where, m and n are the branches m, n=2,3,……N

III. Results and Discussions

To analyze the impact of SWTG-SPV in BEC 15 bus distribution system, fixed point iterative based power flow algorithm has been modelled in OpenDSS. SLD is Modelled based on three phase modelling of load, lines & transformer. Further, Probabilitive distribution of SWTG, SPV, & bus loads are formulated. Table-1 indicate the computational characteristics of distribution system of BEC 15 bus and Europe LV distribution system. LV buses with SWTG-SPV results the voltage above 1.05 pu and losses of 3.375%.

IV. Conclusion & Future Enhancement

This work proposes a stochastic assessment method based on aggregated & SVD cluster of SWTG-SPV in practical unbalanced distribution system using OpenDSS.

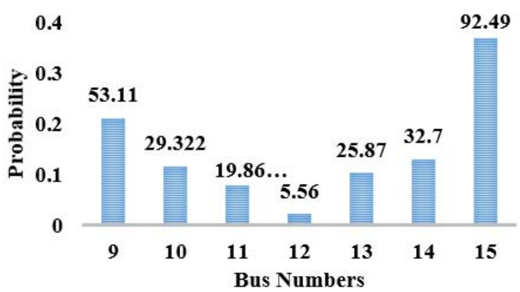

Fig. 2. Probability to reallocate the SPV in BEC 15 Bus System

TABLE-1: COMPUTATIONAL CHARACTERISTICS

Sl.	**BEC 15 Bus Distribution System**		**Europe LV Network [IEEE PES Resource]**	
	Without SVD	***With SVD***	***Without SVD***	***With SVD***
Probabilistic Voltage Issues	P(X≥x) =0.25	P(X≥x) =0.05	P(X≥x) =0.45	P(X≥x) =0.14
Phase	Y & B phase at >70% penetration	All three phase voltages are in within the limit	All three phases 50-90% penetration	All three phase voltages are in within the limit
Thermal Loading	P(X≥x)=0.20	P(X≥x)=0.10	P(X≥x)=0.17	P(X≥x)=0.12
TPL	7.5 kW	0.18kW	18.3 kW	12.4 kW
% of losses	3.37%	0.07%	8.16%	5.43%
Iterations	02	02	04	04
Time in sec	1.5	02	6.5	8.29

Fixed point iterative algorithm used for formulation of three phase power flow analysis. Allocating and aggregating based on IEC standards with probabilistic clustering of DERs. Monte-carlo simulation is considered to cater the uncertainties of DERs and bus loads. The proposed method applied to real-time BEC 15 bus distribution system. In that, voltage and thermal loading maintains within the limit by clustering based on probabilistic power-generation balance. Further, proposed method tested on IEEE 15 & Europe LV Network bus system and results indicating the relative errors of voltage about 0.07. Therefore, this approach helps to assess the impacts of DERs and frame the distribution system as efficient μ-Grid.

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