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Distributed Energy System Automation Using Distributed Intelligence for Power Quality Supply

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ABSTRACT
Load flow analysis of power distribution network based on distributed intelligence introduces remotely distributed processors to power distribution systems. It develops a technique that efficiently controls a distribution system and enormously increases reliability as the steady state operating mark of unbalanced power system can be precisely calculated to allow system operators make proper control decisions. The technology in distribution network operated today makes it impossible to run an efficient and reliable system that minimizes power loss while maximizing the degree of load served. The deterministic method was used inanalyzing the power flow in this work. The model in this power system corresponds with the Gauss-sidel method of iteration. The work is implemented usingMatlab's power of computation and LabView's power of communication. The need for a systemto implement this method determined the programs and structures selected. The robust power distribution system was sectioned without neglecting any part of the network, component models for distributed analysis was developed, convergence properties where investigated and results of simulation for a distributed power system was presented. Results showed that the proposed method converges consistently with resultof an un-sectioned network;this validates the correctness of themodels and the algorithm. The total iteration time, total iteration counts and maximum error reduced with the introduction of intelligent devices and increase in number of sections. With the result obtainedsystem operators can effectively control, protect and calculate the operating state of distribution networks at ever increasing reliability demand.
KEYWORDS*: Distributed energy system, network sectioning, power reliability, system automation, power system intelligence.*

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I. INTRODUCTION

The connectionto electrical energy for most industries, institutions and residence worldwide is the power distribution system. In modern societies the distribution system must be operated such that low real power losses and high level reliability is maintained by system operators under ever increasing demand. The aim of this work is to advance a new method to precisely calculate and operate a distribution system at maximum effectiveness and reliability which diminishes real power loss at the same time boosting the number served loads.

As defined by the Institute of Electrical and Electronics Engineers(IEEE), automated distribution is a network that allows an electric utility to monitor, coordinate and operate the distribution network in real time from a remote location [1]. System managers and local controllers need data about the distribution system operating state to make correct operation decisions. The methodology to determinethe operating state of a power distribution network is the distribution power flow. The processor distribution in this work is designed to imitate the growing existence of distributed intelligent devicesacross distribution networks.

This scheme has seen limited implementation despite its proven advantages due to inadequate computational capacity and complex electric power hard ware needed to compute and execute proper control decisions. By utilizing the processing power of intelligent devices in distribution network this obstacle can be overcome. Some of the intelligent devices seen in distribution systems are; Network Protection Relays, Feeder Terminal Unit (FTU) and Distribution Generators (DG). Due to the presence of on board computer processing units (CPU) in these devices they tend to be capable of monitoring, actuating and communicating within the network.

Distributed study of power distribution system was done previously. Earliest attempt was aimed at minimize computational duration of the power distribution problem where the result was calculated at a centralized base on several processors. In this work the distributed processors have a comprehensive view of the operative state of the distribution system.

II. METHODOLOGY

Deterministic method was used in the power flow analysis for this research.Models in the power system correspond with the Gauss-sidel method of iteration. The distribution network was sectioned; these sections were developed on the grounds of their ability to measure, ability to control or the area controlled by each system component. Sectioning was done strategically to show the true allocation of protecting, controlling and measuringcomponentsacross this power system. See fig 3.1 and 3.2 below.

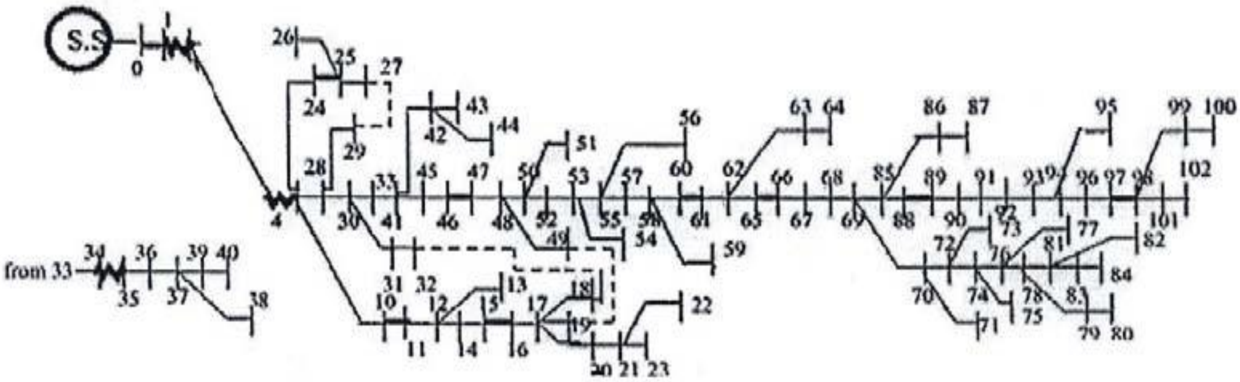

Figure 1.1102bus Un-Sectioned distribution power network

Table 1.1 showing sectioning of the distribution network

SECTIONS	BUSES
Section 0	1–4
Section 1	4–69
Section 2	4–22
Section 3	69–102
Section 4	69–84

Equivalent Source Model

An equivalent source model is necessary for every system section apart from the section with the sub-station. The valuation of every equivalent voltage from the source bus is determined by the load bus equivalent voltage at the adjoining upstream section.

$$V_{i,0}^{(k)} = V_{i-1,eq.\ load}^{(k)}$$

Where:

$V_{i,0}^{(k)}$: complex (n_{ph}x 1), multi-phase voltage vector of the equivalent source bus, updated section$i$, iteration k

$V_{i-1,eq.\ load}^{(k)}$: complex (n_{ph}x 1), multi-phase voltage vector of the equivalent load bus ofcorrespondent upstream section$i$-1, iteration k

K : number of iteration.

Equivalent Load Models

For each section the equivalent load was calculated by carrying out a conventional power flow on the sectionmaking use of updated figures of the corresponding source and load quantities.

Constant current load model on the equivalent load bus at adjoining upstream section for sections having all constant current loads is given as;

$$I_{eq.i}^{(k)}(V^{(k)}) = \sum_{\forall br \in B_i} I_{i,br}^{(k)}\left(V^{(k)}\right)$$

Where:

$I_{eq.i}^{(k)}(V^{(k)})$: complex (n_{ph}x 1) multi-phase equivalent current injectedvector, section$i$, iteration k

$\boldsymbol{I_{i,br}^{(k)}}$ **:** complex (n_{ph}x 1) multi-phase current on branch *br*, section*i*,iteration *k*
$\boldsymbol{B_i}$: group of each branch linked directly to the source bus, section i
$\boldsymbol{V^{(k)}}$: complex (n_nx 1) voltage vector of the sectioned network, iteration *k*.

Constant impedance load model on the equivalent load bus of theadjoining upstream section for a sections having all constant impedance loads is given as;

$$\boldsymbol{Y_{eq,i}^{(k)}(v^{(k)}) = 1./\left(V_{i,0}^{(k)}./I_{eq,i}^{(k)}\right)}.$$

Where:

$\boldsymbol{Y_{eq,i}^{(k)}(v^{(k)})}$ **:**Complex (n_{ph}x *1*) multi-phase admittance vector of the equivalent bus, section*i* , iteration *k*
$\boldsymbol{V_{i,0}^{(k)}}$**:** Complex ($n_{ph}$x *1*) multi-phase voltage vector of the equivalent source bus, section*i*, iteration *k.*
./: Element-wise division

Constant power load model on the equivalent load bus of the adjoining upstream section for sections having all constant power loads is given as;

$$\boldsymbol{S_{eq.i}^{(k)}(V^{(k)}) = V_{i,0}^{(k)}.*\left(I_{eq.\ i}^{(k)}\right)^*}.$$

$\boldsymbol{S_{eq.i}^{(k)}(V^{(k)})}$**:**Complex ($n_{ph}$x *1*) multi-phase equivalent power injected Vector, section*i*, iteration *k*
. * : Element-wise multiplication
Superscript*** :**complex conjugate.

Distribution System Model

To establish a model for the sectioned network the equivalent source and equivalent load component models were implemented. Distributed system model was first deduced through equivalent impedance loads, then equivalent power injection loads and equivalent current injections loads.

$$\begin{bmatrix} Y_{00} & 0 & 0 & 0 \\ 0 & Y_{11} & 0 & 0 \\ 0 & 0 & \ddots & 0 \\ 0 & 0 & 0 & Y_{n_p n_p} \end{bmatrix} \begin{bmatrix} V_0 \\ V_1 \\ \vdots \\ V_{n_p} \end{bmatrix} = \begin{bmatrix} I_0(V) + I_{eq.1}(V) \\ I_1(V) + I_{eq.2}(V) \\ \vdots \\ I_{n_p}(V) \end{bmatrix}$$

Where

Y_{ii}: complex ($n_m^i \times n_m^i$) admittance matrix, section*i*
n_m^i: number of nodes, section*i*
V : complex ($n_n \times 1$) voltage vector of the sectioned system

Having developed the models, an algorithm for computing the system operating state was designed.The distributed power flow method in this work analysis the entire system conditions by iteratively drivinga conventional power flow on everysection with the aid of processors distributed for communication of results.

Convergence Criteria

For the iteration to converge consecutively the boundary bus voltage should be within a specific tolerance ($\varepsilon=10^{-10}$). For the equivalent source bus, the convergence criterion is given as;

$$\left||V_{i,0}^{(k+1)}| - |V_{i,0}^{(k)}|\right| \leq \varepsilon_1 \quad \& \left|\angle V_{1,0}^{(k+1)} - \angle V_{1,0}^{(k)}\right| \leq \varepsilon_2 \forall\, i = 1,2,\dots,n_p$$

Where

$|V_{i,0}^{(k)}|$: voltage magnitude of equivalent source bus, section*i*
$\angle V_{1,0}^{(k)}$: voltage phase angle of equivalent source bus, section*i*
$\varepsilon_{1,2}$: voltage magnitude and phase angle convergence tolerance.

For the equivalent load bus the convergence criterion is given as;

$$\boldsymbol{\left||V_{i,eq.load}^{(k+1)}| - |V_{i,eq.\ load}^{(k)}|\right| \leq \varepsilon_1 \& \left|\angle V_{1,eq.\ load}^{(k+1)} - \angle V_{1,eq.\ load}^{(k)}\right| \leq \varepsilon_2 \forall\, i = 1,2,\dots,n_p}$$

Where:

$\boldsymbol{|V_{i,eq.\ load}^{(k)}|}$ **:** Voltage magnitude for equivalent load bus, section*i*

$\angle V_{1,eq.\ load}^{(k)}$: voltage phase angle for equivalent load bus, section*i*

III. RESULT PRESENTATION AND DISCUSSION

Results and discussion are presented to reflect the accuracyof the proposed distributed power flow against the solution of the un-sectioned power flow. The number of iterations and the time required forconvergence of the distributed power flow are shown. A set of simulations were selected to show the impact the load model and the number of sections have on the accuracy and computation time of the distributed analysis.

Simulations for un-sectioned original system, three sections system and five sections system was carried out in which the entire test system loads were modeled as a constant impedance loads, constant current loads or constant power loads.

The load model applied for each load of the un-sectioned original system was first chosen as constant impedance. Table 1.3 shows the summary of test results for the voltage profile comparison of the original system, the three sections system and the five sections system. Using an implicit Z-Bus Gauss power flow at each processor the sectioned system was solved with the distributed power flow algorithm. From the table the three sections and five sections system converge to the same solution as the original system for the three phase bus voltage with voltage magnitude values of 0.9767, 0.9766 and 0.9768 respectively.

Table 1.2 Simulation Results for the Original V, Three Sectioned V and Five Sectioned Voltage.

		Original V		**Three Sectioned V**		**Five Sectioned V**	
Bus	**Ø**	**$\|V\|$, pu**	**$\angle V^0$**	**$\|V\|$, pu**	**$\angle V^0$**	**$\|V\|$, pu**	**$\angle V^0$**
4	A	0.9768	-3.4998	0.9767	-3.4948	0.9766	-3.4942
	B	0.9690	-123.90	0.9698	-123.81	0.9692	-123.78
	C	0.9720	116.37	0.9722	116.41	0.9721	116.44
69	A	0.9545	-5.1258	0.9535	-5.2280	0.9531	-5.2280
	B	0.9404	-126.06	0.9408	-125.99	0.9410	-125.97
	C	0.9544	114.54	0.9533	114.50	0.9528	114.80

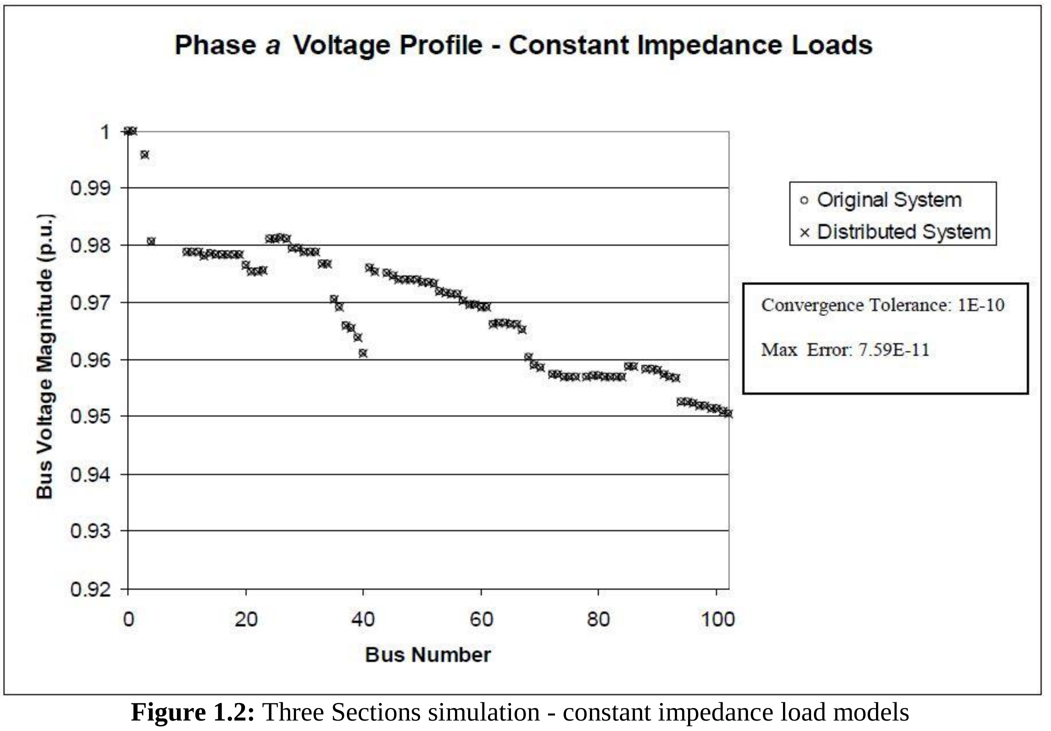

Figure 1.2: Three Sections simulation - constant impedance load models

Figure 1.2 presents the power flow solutions for the phase *a* voltage magnitude at each bus of the original system. The equivalent loads were modeled at each section as constant impedance. 11 iterations were carriedbefore the distributed power flow converged to a solution, with an average of 46.120 seconds over all trials on the given test platform. Figure 1.2shows the distributed power flow results for the phase *a* voltage magnitude at each bus. At the converged solution, the three-phase bus voltages converged within the convergence tolerance, to the same solution as the power flow on the original system. The graph shows the max absolute error of voltage magnitude between the distributed power flow and a power flow on the original un-sectioned network.

Table 1.3: Overview of Simulation outcome.

Section Number	Load Models	Maximum Error	Number of Iterations	Mean Total Time (s)
3	Constant Impedance	7.56E-11	11	46.120
3	Constant Current	4.59E-11	13	56.243
3	Constant Power	8.51E-11	7	27.017
5	Constant Impedance	1.89E-14	11	40.261
5	Constant Current	1.18E-12	10	36.619
5	Constant Power	2.95E-11	6	24.807
5	Mixed –Z and P	2.49E-11	10	41.710

IV. DISCUSSION OF RESULT

From the results shown the distributed power flow converges consistently with results of a conventional power flow subject to set changes on the un-sectioned network including differing load models and number of sections. The results confirm the models and algorithm are correct subject to varying dynamics. Differing dynamics influences the iterationcounts and algorithm convergence total time as seen in the result. Table 1.3 below gives an overview of the simulation outcome.

For the simulation of constant impedance loads both the 3 and 5 sectioned systems maintain the same number of iterations though the total time set for convergence decreased with increase in the number of sections. This speed-up would be expected with the theory that communication channels experience time delays which are assumed identical for each case. Following the timing models shown in this work, with an identical network time delays, the variation in total time was considered while analysis every processor. Systems included in two of the three sections were bigger in the 3 sections network compared to those included in the 5 sections networks. The complex natureof the load flow problem at every section decreases with increase in the section number which led to a reduced total convergence time. In the results of constant current loads,number of iterations and total timedecreased with an increase in the number of sections number. The decreasedtotal time and number of iteration was in view of the fact that less iterationminimizes lags in communicating and computing within the network. Constant power loads showed the same results. The increase in number of sections decreases the complex nature of the power flow analysis at every section which results in a reduction of total convergence time as seen in the table, hence the reduction in iteration counts and simulation average total time.

V. CONCLUSION.

The research has provided component models, analysis of convergence profile and results of simulation for a distributed power flow problem solver. Simulation results when in contrast with that of a conventional power flow on a test platform, presented a distributed analysisthat converge to equal result as a conventional power flow, proving the validity of the models and algorithm used in this work. With the simulation results obtained about the operating state of the distribution system, the system operator can accurately measure, adequately protect and efficiently control the distribution power system while increasing the range of loads served.

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