Minimization of Losses Using Genetic Algorithm in Distributed Slack Bus Model

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***Abstract*— Powersystem environments are changingrapidly,e.g.,steady, rapidsignificant increasein distributedgeneration. Therefore, planning and strategy should be modified for effective Load Flow studies.Thispaper evaluates the multipleslackbus assumption which is typically employed in steady-stateTransmissionpowerflows and illustrates the advantages and effectiveness of Distributed Slack Bus Model while distributing the system losses among all the generators as per present requirements of minimization of lossesusing Genetic Algorithm.Simulation results and tables are also given for better understanding.**

Keywords— **Participation Factor (pf), Distributed Generators(DG), Distributed Slack Bus(DSB), Newton-Raphson Load Flow(NRLF), Genetic Algorithm (GA).**

I. INTRODUCTION

Recent energy crisis in conventional energy sources has created the need to have non-conventional energy sources in the Power system network. As a result the implementation of non-conventional energy resources are increasing day by day.We have to change our conventional Load Flow procedure to accommodate all the energy sources effectively and fruitfully. The effective implementationcan be done using DSB model.

A reference bus or slack bus is defined as the V-δ bus, which is used for balancing the active power |P| and reactive power |Q| in the network system when performing Load Flow Study in Power System.

Swing Bus is to provide whole system loss by absorbing or byinjecting active or reactive power from or to the system. Though thedescription ofpower flow study is true for a deterministic solution, it has a drawback while dealing with the uncertain variables, the swing bus shouldtake out all uncertainties arising in the network and thus, will possess wide nodal power probability distributions in the system.

In theold-fashionedload flow studies with single swing bus model, one bus is selected to take out all system losses, though practically there is no such swing bus in real power systems network. There it may considerablytwistprojected power flows. So to deliverfaithful power flow, power economic analysis (Kamh & Iravani, JUNE 2012)with distributed slack bus model (DSB) has been adopted. Here slack bus is only for the reference of the bus voltage magnitude and angle.

In 2005,Tong proposed the distributed slack bus model (Tong & Miu, A Network-Based Distributed Slack Bus Model for DGs in Unbalanced Power Flow Studies, MAY 2005). After a long period of 7 years,on 2012 another paper came by M. Zakaria Kamh on sequence frame based model which demonstrated the use of energy management of active distribution network (Kamh & Iravani, JUNE 2012).

This paper demonstrates the applications of DSB model based on the participation factors (pf). This model is entrenched in aload flow solver and the pf quantify the real power output from the DGs as well as other generating buses including the slack bus, contributed to loss.Here in this paper, I have applied Genetic Algorithm to minimize losses of the system.Therefore not only loss is minimized but also we can minimize the cost as cost is proportional to loss.

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The paper organized as follows. Section II describes a summary of the model of the system and power flow equations. Power Flow solving and Flowchart are illustrated in section III. The results and comparative studies are given in SectionIV. Chapter V is the conclusion. The paper ended with chapter VI.

II. CONCEPT OF DISTRIBUTED SLACK BUS

A Network based distributed slack bus model (Tong & Miu, A Network-Based Distributed Slack Bus Model for DGs in Unbalanced Power Flow Studies, MAY 2005)is presented here for the slack bus as well as other generating buses including DGs whose real power injections can be adjusted.

➢ Concept of Participation Factor:

We cannot supposed to have all generators in power systems to be allowed for adjusting their real power injections, as they may be small machines and thy may not have necessary control mechanisms. Therefore we consider two types of generators:

- Non-participating generators (simple PQ model)
- Participating generators (P$|V|$model)

Therefore, only the set of participating generators with controllable real power outcomeshave to be modelled using pf.

Now, participation factor (pf) (Tong & Miu, Participation Factor Studies for Distributed Slack Bus Models in Three-Phase Distribution Power Flow Analysis, 2006) is defined as follows,

$$pf_i = P_{Gi}^{loss} / P_{loss} \qquad i = 1,2,3 \dots m \qquad (1)$$

$$where: \sum_{i=1}^{n} pf_i = 1 \qquad (2)$$

Where:
n= number of buses;
m=number of generator buses(including slack buses);
(n-m)=number of load buses;

$$P_{Gi}^{loss} = P_{Gi}^{loss,a} + P_{Gi}^{loss,b} + P_{Gi}^{loss,c} \qquad (3)$$

And

1	substation bus index
(m-1)	number of participating generators
P_{loss}	Total power loss (real) in the system
P_{Gi}^{loss}	Losses associated with generator 'i'
$P_{Gi}^{loss,p}$	Losses associated with generator i, phase p

III. SIMPLE POWER FLOW SOLVER AND FLOWCHART

Now, it is crystal clear that,

$$\sum_{i=1}^{m} pf_p^i + \sum_{i=m+1}^{N} pf_p^i = 1 \qquad (4)$$

As the participation factors for the load buses are zero, as they would not participate for supplying losses, therefore

$$\sum_{i=m+1}^{N} pf_p^i = 0 \qquad (5)$$

Therefore,

$$\sum_{i=1}^{m} pf_p^i = 1 \qquad (6)$$

Now, the unknowns are,

1. P_{loss}
2. $\theta_i^a \qquad i = 1, \dots, m;$
3. $\theta_i^p, V_i^P \qquad i = m+1, \dots, n \text{ and } p = a, b, c;$

Now, from normal NRLF procedure we can get the initial value of P_{Loss}

Now, the equations are,
For the substation buses:

$$f_{Pi} = P_{Gi}^{load} + pf_i P_{Loss} - \sum_{p=a}^{c} P_{Di}^p - \sum_{p=a}^{c} P_i^p = 0 \qquad (7)$$

Where,
P_{Gi}^{load} is the load associated with the generator i.
$\sum_{p=a}^{c} P_{Di}^p$ is the local load associated to bus i.

For (n-m) load buses:

$$f_{Pi}^p = -P_{Di}^p - P_i^p = 0 \qquad i = (m+1), (m+2), \dots, n \quad (8)$$

$$f_{Qi}^p = -Q_{Di}^p - Q_i^p = 0 \qquad i = (m+1), (m+2), \dots, n \quad (9)$$

Where,

$$P_i^p = |V_i^p| \sum_{k=0}^{n} |V_k^p| \left[g_{i,k}^p \cos(\theta_i^p - \theta_k^p) + b_{i,k}^p \sin(\theta_i^p - \theta_k^p) \right] \qquad (10)$$

$$Q_i^p = |V_i^p| \sum_{k=0}^{n} |V_k^p| \left[g_{i,k}^p \sin(\theta_i^p - \theta_k^p) + b_{i,k}^p \cos(\theta_i^p - \theta_k^p) \right] \qquad (11)$$

P_{Di}^p, Q_{Di}^p are real load &reactive load on bus *i*, in phase *p*.

Now, let us have the equations in matrix form which can clarify the whole thing in a better way.

$$-F = J\Delta x \qquad (12)$$

$$\begin{bmatrix} f_{P0} \\ f_{P1} \\ \vdots \\ f_{Pm} \\ f_{P_{m+1}}^a \\ \vdots \\ f_{Pn}^c \\ f_{Q_{m+1}}^a \\ \vdots \\ f_{Qn}^c \end{bmatrix}$$

$$
=
\begin{bmatrix}
pf_1 & \frac{\partial f_{p1}}{\partial \theta_2^a} & \cdots & \frac{\partial f_{p1}}{\partial \theta_{m-1}^a} & \frac{\partial f_{p1}}{\partial \theta_m^a} & \cdots & \frac{\partial f_{p1}}{\partial \theta_n^c} & \frac{\partial f_{P1}}{\partial |V_{m+1}^a|} & \cdots & \frac{\partial f_{P1}}{\partial |V_n^c|} \\
pf_2 & \frac{\partial f_{p2}}{\partial \theta_2^a} & \cdots & \frac{\partial f_{p2}}{\partial \theta_{m-1}^a} & \frac{\partial f_{p2}}{\partial \theta_m^a} & \cdots & \frac{\partial f_{p2}}{\partial \theta_n^c} & \frac{\partial f_{p2}}{\partial |V_{m+1}^a|} & \cdots & \frac{\partial f_{p2}}{\partial |V_n^c|} \\
\vdots & \vdots & \ddots & \vdots & \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\
pf_{m-1} & \frac{\partial f_{pm-1}}{\partial \theta_2^a} & \cdots & \frac{\partial f_{pm-1}}{\partial \theta_{m-1}^a} & \frac{\partial f_{pm-1}}{\partial \theta_m^a} & \cdots & \frac{\partial f_{pm-1}}{\partial \theta_n^c} & \frac{\partial f_{pm-1}}{\partial |V_{m+1}^a|} & \cdots & \frac{\partial f_{pm}}{\partial |V_n^c|} \\
pf_m & \frac{\partial f_{Pm}^a}{\partial \theta_2^a} & \cdots & \frac{\partial f_{Pm}^a}{\partial \theta_{m-1}^a} & \frac{\partial f_{Pm}^a}{\partial \theta_m^a} & \cdots & \frac{\partial f_{Pm}^a}{\partial \theta_n^c} & \frac{\partial f_{Pm}^a}{\partial |V_{m+1}^a|} & \cdots & \frac{\partial f_{Pm+1}^a}{\partial |V_n^c|} \\
\vdots & \vdots & \ddots & \vdots & \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\
0 & \frac{\partial f_{Pn}^c}{\partial \theta_2^a} & \cdots & \frac{\partial f_{Pn}^c}{\partial \theta_{m-1}^a} & \frac{\partial f_{Pn}^c}{\partial \theta_m^a} & \cdots & \frac{\partial f_{Pn}^c}{\partial \theta_n^c} & \frac{\partial f_{Pn}^c}{\partial |V_{m+1}^a|} & \cdots & \frac{\partial f_{Pn}^c}{\partial |V_n^c|} \\
0 & \frac{\partial f_{Qm+1}^a}{\partial \theta_2^a} & \cdots & \frac{\partial f_{Qm+1}^a}{\partial \theta_{m-1}^a} & \frac{\partial f_{Qm+1}^a}{\partial \theta_m^a} & \cdots & \frac{\partial f_{Qm+1}^a}{\partial \theta_n^c} & \frac{\partial f_{Qm+1}^a}{\partial |V_{m+1}^a|} & \cdots & \frac{\partial f_{Qm+1}^a}{\partial |V_n^c|} \\
\vdots & \vdots & \ddots & \vdots & \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\
0 & \frac{\partial f_{Qn}^c}{\partial \theta_2^a} & \cdots & \frac{\partial f_{Qn}^c}{\partial \theta_{m-1}^a} & \frac{\partial f_{Qn}^c}{\partial \theta_m^a} & \cdots & \frac{\partial f_{Qn}^c}{\partial \theta_n^c} & \frac{\partial f_{Qn}^c}{\partial |V_{m+1}^a|} & \cdots & \frac{\partial f_{Qn}^c}{\partial |V_n^c|}
\end{bmatrix}
$$

$$
X \begin{bmatrix} \Delta(P_{loss}) \\ \Delta\theta_1^a \\ \vdots \\ \Delta\theta_m^a \\ \Delta\theta_{m+1}^a \\ \vdots \\ \Delta\theta_n^c \\ \Delta|V|_{m+1}^a \\ \vdots \\ \Delta|V|_n^c \end{bmatrix} \qquad (13)
$$

So, it is crystal clear that this is just like the Newton-Raphson method. The Jacobian matrix is also like the normal N-RLF method, only the difference is the 1st row and 1st column. So we can say it as a modified NRLF method.

Now, we will minimize the losses using GA. Practically, we will change the participation factor randomly, and thus we will change the generations also. We will optimize the loss using GA to find out the values of the participation factors for which the losses will be optimized.

Now here is the tool box for GA;

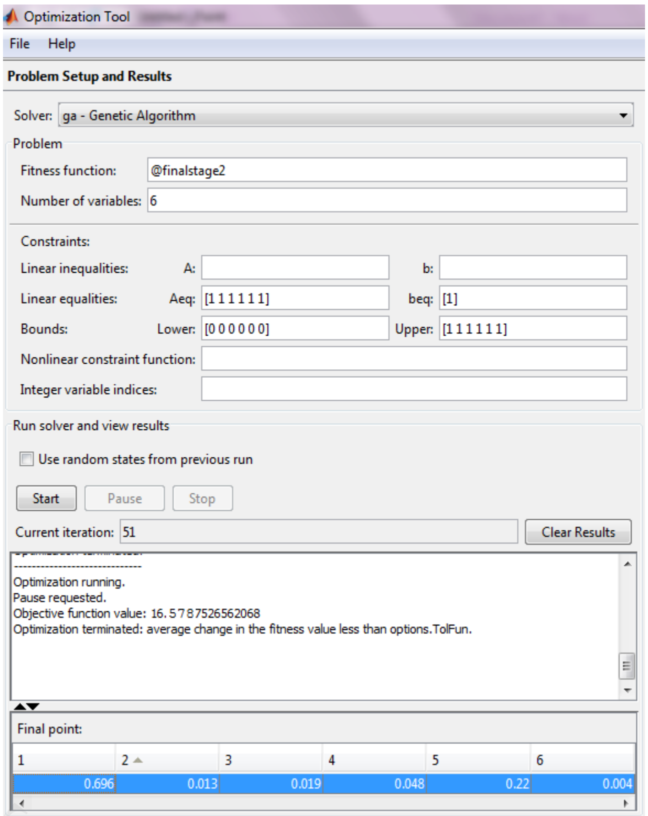
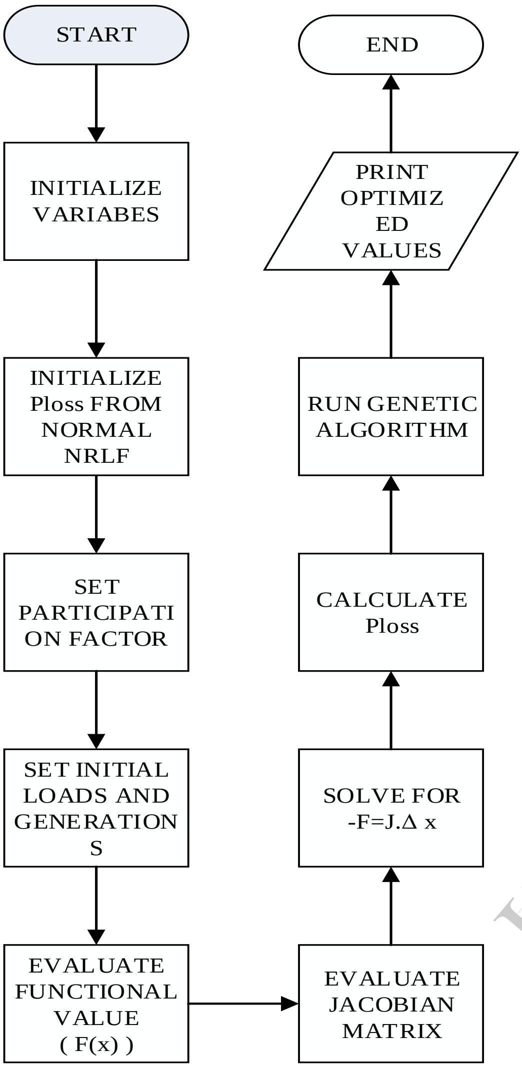


Figure 1 GA Toolbox

Flow chart:

- Initialize all the variables along with iterative counters.
- Set the participation factors
- Set initial generation set points.
- Evaluate functional values from taylor series expansion.
- Check the tolerance limit.
- Evaluate Jacobian matrix for modified NRLF.
- Solve for -F=J.Δx.
- Update the values of the variables by x=x+Δx
- Check the generation limits of all the generators
- Be sure that all are within limit.
- All these limits will be checked through Genetic Algorithm
- If any generator found to be out of the limit then make it' generation fixed to its marginal value and set the participation factors again and follow this very path unless or until it converges.
- Now in case of GA all these constraints will be taken care in the programme.

The flow chart is:



IV. RESULTS AND COMPARATIVE STUDY

Simulation results are as follows;

Table 1: FOR STANDARD 14 BUS SYSTEM

NO. OF GEN	NORMAL NRLF(SINGLE SLACK BUS)	DISTRIBUTED SLACK BUS SYSTEM	GA LOSS MINIMIZATION
GEN 1	236.891	226.648	221.484
GEN 2	18.3	23.421	32.903
GEN 3	11.2	16.321	11.200
LOSS	15.502	14.803	14.2419(mean)

Table 2: PARTICIPATION FACTORS

No of GEN	Participation factor for normal NRLF	Participation factor for distrb. slack bus method	Participation factor for loss min. With GA
GEN 1	1	0.333	0.004
GEN 2	0	0.333	0.027
GEN 3	0	0.333	0.970

Table 3: FOR STANDARD 30 BUS SYSTEM

NO. OF GEN	NORMAL NRLF(SINGLE SLACK BUS)	DISTRIBUTED SLACK BUS SYSTEM	GA LOSS MINIMIZATION
GEN 1	238.675	224.428	232.779
GEN 2	57.560	60.409	57.784
GEN 3	24.560	27.409	24.887
GEN 4	35.000	37.849	35.827
GEN 5	17.930	20.779	21.722
GEN 6	16.910	19.759	16.979
LOSS	17.235	16.853	15.3482 (mean)

Table 4: PARTICIPATION FACTORS

No of GEN	Participation factor for normal NRLF	Participation factor for distrb. slack bus method	Participation factor for loss min. With GA
GEN 1	1	0.1666	0.013
GEN 2	0	0.1666	0.002
GEN 3	0	0.1666	0.24
GEN 4	0	0.1666	0.244
GEN 5	0	0.1666	0.246
GEN 6	0	0.1666	0.255

V. CONCLUSIONS

Here in this paper it has been discussed that how to use distributed slack bus method along with loss minimization using Genetic Algorithm. This procedure provides us with a dependable solution of a load flow loss minimization problem.In case of normal load flow problem, slack bus provides the whole loss, hence that bus may get overloaded. But here, we distribute the losses among all the generators and also minimize the loss, so that we can overcome that overloading problem. Moreover, we are also reducing the losses, so we are reducing the energy wastages, which is cost effective also. Again for distribution system it is much more cost effective as we are reducing the generation of the slack bus to reduce loss, which is nothing but substation bus in distribution system. Therefore more cost effective in case of distribution system.

VI.REFERENCES

1. Expósito, A. G., Ramos, J. L., & Santos, J. R. (MAY 2004). Slack Bus Selection to Minimize the System Power Imbalance in Load-Flow Studies. *IEEE TRANSACTIONS ON POWER SYSTEMS , 19* (2), 987-995.
2. Kamh, M. Z., & Iravani, R. (JUNE 2012). A Sequence Frame-Based Distributed Slack Bus Model for Energy Management of Active Distribution Networks. *IEEE TRANSACTIONS ON SMART GRID , 3* (2), 828-836.
3. Tong, S., & Miu, K. N. (MAY 2005). A Network-Based Distributed Slack Bus Model for DGs in Unbalanced Power Flow Studies. *IEEE TRANSACTIONS ON POWER SYSTEMS , 20* (2), 835-842.
4. Tong, S., & Miu, K. N. (2006). Participation Factor Studies for Distributed Slack Bus Models in Three-Phase Distribution Power Flow Analysis. *IEEE.*
5. Tong, S., Kleinberg, M., & Miu, K. (2005). A Distributed Slack Bus Model and Its Impact on Distribution System Application Techniques. *Center for Electric Power Engineering.* Philadelphia, PA 19104, USA.

[6] T. Werner and R. Remberg, "Technical, economical, and regulatory aspects of virtual power plants," in Proc. 3rd Int. Conf. Electr. Utility Deregulation Restructuring Power Technol. (DRPT), 2008.

[7] R. Lasseter, "Microgrids and distributed generation," J. Energy Eng. , vol. 20, no. 3, pp. 144-149, 2007.

[8] F. Kateraei and M. Iravani, "Transients of a micro-grid system with multiple distributed energy resources," in Proc. Int. Conf. Power Syst. Transients (IPST), 2005.

[9] F. Gao and M. Iravani, "A control strategy for a distributed generation unit in grid-connected and autonomous modes of operation," IEEE Trans. Power Del. , vol. 23, no. 2, pp. 850-859, 2008.

[10] J. Meisel, "System incremental cost calculations using the participation factor load-flow formulation," IEEE Tran. Power Syst., vol. 8, no. 1, pp. 357-363, 1993.

[11] S. Tong and K. Miu, "A participation factor model for slack buses in distribution systems with DGs," in Proc. IEEE Power Eng. Soc. Transm. Distrib. Conf., Dallas, TX, 2003.

[12] C. Schauder and H. Mehta, "Vector analysis and control of advanced static VAr compensators," IEE Proc. Gener., Transm., Distrib., vol. 140, no. 4, pp. 299-306, 1993.