UNIVERSITY OF NAIROBI
SCHOOL OF ENGINEERING
DEPARTMENT OF ELECTRICAL AND INFORMATION
ENGINEERING

DYNAMIC LOAD FLOW STUDIES WITH RENEWABLE ENERGY

PROJECT INDEX: PRJ 052

BY

KHAEMBA SIMIYU SAMUEL
F17/1450/2011

SUPERVISOR: PROF. N. O. ABUNGU
EXAMINER: MR. P.M. MUSAU
INTRODUCTION

The flow of active and reactive power is called power flow or load flow. Load flow solution – is a solution of the network under steady state operation subjected to certain inequality constraints e.g. node voltages, reactive power generation of generators, the tap settings of the tap changing transformer under load etc. Under which the system operates.

Load flow studies – are conducted at the stage of planning, operation and control. They are used to determine the phase angle of load buses and active and reactive power injected at the buses and also active and reactive power flows over transmission lines.

Renewable energy is energy that utilizes sources that are continually replenished by nature to produce usable forms of energy e.g. Solar and wind energy.
Project Objectives

The main aim objective of this project is to introduce the dynamic load flow methods incorporating renewable energy sources. The conventional methods are first introduced and then the effects of renewable sources to these method are studied. The most appropriate method for load flow with renewable energy is demonstrated using MATLAB as the programming platform. For this project, the improved Newton-Raphson method was proposed. The effects of renewable energy on the system security and stability are considered in this project too.
Research Questions

What are the dynamic load flow methods?
What are the effects of renewable energy sources on load flow methods?
What are the effects of renewable energy on the system security and stability?

Scope

The project covers the effects of wind and solar energy on the load flow. The solution to the challenges due to the wind and solar energy on the load flow are presented using the Improved Newton Raphson method. The security and stability of the system due to these renewables are also discussed.
Computer simulation using MATLAB will be used to analyse the results.
Literature Review Cont’d
Solving the Load Flow Problem

Properties of load flow solution method

High computational speed
Low computer storage
Reliability of solution
Versatility
Simplicity.

The type of solution required from a load flow also determines the method used: accurate or approximate unadjusted or adjusted offline or online single case or multiple cases.
Literature Review Cont’d
Effects of Renewable Sources on Load Flow

Solar Energy

Technical concerns with integrating higher penetrations of photovoltaic (PV) systems include grid stability, voltage regulation, power quality (voltage rise, sags, flicker, and frequency fluctuations), and protection and coordination.

The current utility grid is initially designed to accommodate power flows from the central generation source to the transmission system and eventually to the distribution feeders. At the distribution level, the system is designed to carry power from the substation toward the load.

Renewable distributed generation, particularly solar PV, provides power at the distribution level challenging this classical paradigm. As these resources become more common place the nature of the distribution network and its operation is changing to handle power flow in both directions.

The load flow parameters and power flow direction on the grid system become more difficult to be predicted. Power flow changes from uni-directional power flow to bi-directional power flow. Based on, the current conventional grid system is not ready for large-scale distributed generation.
Wind Energy

Wind resources are usually at different locations than conventional power stations. Hence, power flows are considerably different in the presence of a high amount of wind power and power systems are typically not optimized for wind power transport. This aspect can be more or less severe in different countries.

Wind generators are usually based on different generator technologies than conventional synchronous generators.

Wind generators are usually connected to lower voltage levels than conventional power stations. Most wind farms are connected to sub transmission (e.g. 110kV, 66kV) or even to distribution levels (e.g. 20kV, 10kV) and not directly to transmission levels (> 110kV) via big step-up transformers as in case of conventional power stations.
Dynamic Load Flow Studies with Renewable Sources.

Load Flow Methods

- Artificial Intelligence Based
  - Artificial Neural Network Based
  - GA-Based Algorithm
  - PSO-Based Algorithm
  - Branch Current Based
  - Branch Power Based
  - Branch Impedance Based

- Optimization Based
  - Branch Current Based

- Compensated Back/Forward Based

- Super-Position Based
  - Hybrid SP
  - Improved Hybrid SP

- Gauss-Seidel Based
  - Improved Hybrid GS

- Newton Raphson Based
  - Current Injection Method
METHODOLOGY
Introduction

Features of distribution system includes:
Radial and near radial (weakly meshed) in nature
R/X is high compared to transmission systems
The majority share of load demand is supplied by utility substation.
The voltage phase angle in all the buses are negligible
The distribution networks because of the some of the above special features fall in the category of ill-condition.
METHODOLOGY
Why Improved-Newton-Raphson?

Newton based methods require more computations and memory requirements in order to conduct the power flow analysis for distribution systems but has the following merits:

It is not sensitive to the position of the slack bus
Its rate of convergence is fast and therefore requires less number of iterations to obtain the solution.
It is independent of the number of buses of the system hence it can be applied on large practical systems.
The convergence of the method is not affected by the selection of the slack bus; hence there is freedom of distributing the slack bus.
It is more accurate and reliable when used for large systems.
METHODOLOGY
Problem Formulation
Distribution Network Modelling

Distribution Lines
Distribution Transformers
  Core Losses Modelling
  1. The Admittance Matrix
Network load modelling
DG modelling - The DG in networks is noticed by two models:
  1. Non-participating DGs (PQ model).
  2. Participating DG (PV model).
Participation factors and generator domains

Participation factors are proposed to quantify the portion of losses for each generator and network source. These factors, considering the network topology, evaluate the load distribution and source capacities (including DG and network source). The participation factors are shown as below:

\[
\begin{align*}
\text{ participation factor } & = 0,1,2, \ldots, \\
\text{loss associated with generator } i & + \text{loss associated with generator } i \text{ in phase } p
\end{align*}
\]

Where;

\[
\begin{align*}
\sum \text{losses} & = 1, \\
\text{number of participated DGs} & = 1,2, \ldots, \\
\text{total real power losses} & = 1,2, \ldots,
\end{align*}
\]

\(n\): Number of participated DGs in the system

\(P\): Total real power losses in the system

\(P_i\): Loss associated with generator \(i\)

\(P_{ip}\): Loss associated with generator \(i\) in phase \(p\)
It should be noted that in above equations, index 0 belongs to substation. The definition of generator domain is the associate portions of the electrical network, their losses and loads, to different generators. Regarding discussed definition, for each generator:

\[
\begin{align*}
\text{load}_i &= \text{load}_i^0 + \sum_{p=1}^{n_p} \text{load}_{i,p}, \\
\end{align*}
\]

Where:

- \(\text{load}_i\): The load associated with generator \(i\)
- \(\text{load}_{i,p}\): The load associated with generator \(i\) in phase \(p\)
METHODOLOGY
Load Flow Algorithm

The system assumptions expressed as following:
- System has n+1 bus.
- System has m generator buses (PV).
- Bus 0 is the substation bus.
- Generator buses are from number 1 to m.
- Renewable sources are used.

Also the following constraints should be satisfied:

\[
< < <
\]

\[
= | \sum \sum | \begin{bmatrix} \cos(-) + \sin(-) \\ \sin(-) - \cos(-) \end{bmatrix}
\]
Evaluate tap & voltage

Start

K=0

\( K = K + 1 \)

\( ||(\cdot)|| < \)

Convert the DG into PV constant bus with Participating Factor \( K=0 \)

Calculate the Participating factor

Evaluate the generator domain

NO

YES

Calculate the sensitivity factor \( S \) for adjusting Tap

NO

YES

NO

Convert the trespass DG into constant PQ

\( ||(\cdot)|| < \)

\( < < \)

\( < < \)

\( \Delta \)
## RESULTS AND ANALYSIS

<table>
<thead>
<tr>
<th>Bus Number</th>
<th>Injection</th>
<th>Generation</th>
<th>Load</th>
<th>Losses</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MW</td>
<td>MVar</td>
<td>MW</td>
<td>MVar</td>
</tr>
<tr>
<td>14</td>
<td>13.409</td>
<td>30.303</td>
<td>272.409</td>
<td>103.803</td>
</tr>
<tr>
<td>30</td>
<td>2.412</td>
<td>-33.602</td>
<td>191.612</td>
<td>73.598</td>
</tr>
<tr>
<td>57</td>
<td>22.703</td>
<td>-28.764</td>
<td>822.703</td>
<td>163.036</td>
</tr>
</tbody>
</table>
IEEE 14 bus system, the voltage profile was observed to be below 1.06 except at buses 1, 6 and 8 where the per unit voltages were 1.0700, 1.0700 and 1.0800 respectively. This is because the renewables (solar) were introduced at bus 1. The voltage stability margins ought to be $\pm 6\%$, which means the minimum and maximum per unit voltage should be 0.94 and 1.0600 respectively. The voltage profiles at this point can be improved by increasing the load reactive power.

Voltage instability may lead to the collapse of the line. In load flow, reactive power is the power taken by the reactance of the circuit. This power is not actual but flows forth and back (dynamic load flow). Reactive power is the one which is mostly suffered by changes in load demands. The voltage profile can be improved by controlling the reactive power by use of Flexible Alternating Current Transmission (FACTS) whereby Static Var Compensation (SVC) is used for improving voltage stability by connecting it at the weakest node. The algorithm developed was able to keep the voltage below the collapse levels.

For the 30 bus system and 57 bus system, the voltage profiles are shown above in Figures 4.6 and 4.8 respectively. For the 30 bus system, the DGs were introduced at buses 2 (wind energy) and 13 (solar energy), this resulted into the voltage magnitudes being highest at these buses i.e. 1.0000 p.u. The same effect was observed when DGs were introduced in the 57 bus system at buses 2 (wind energy) and at bus 9 (solar Energy).
RESULTS AND ANALYSIS Cont’d

For the IEEE 14 bus system, the runtime was 0.138502 seconds while for the IEEE 30 and 57 bus systems the runtimes were found to be 0.183638 seconds and 0.515460 seconds respectively. The large and complex the power system the more time it takes for the Improved Newton Raphson for distributed generation systems to converge.

Since the configuration changes from passive to active when DGs are integrated into the power system due to the renewables, this necessitates the calculation of line losses. For the above test systems, the line losses were found to be 13.911 MW and 57.986 MVar, 2.412 MW and 9.352 MVar, 28.008 MW and 187.219 MVar for the IEEE 14, 30 and 57 bus system respectively.
CONCLUSION

The proposed method introduces a distribution slack bus model through scalar participation factors by applying the concept of generator domains. The participation factors are incorporated into the three-phase power flow equations.

The presence of RE leads to voltage fluctuations. This has been addressed by the distributed slack bus model as presented in the algorithm by correcting the voltage magnitudes and angles.

The distributed slack bus has an effect of distributing the system losses thereby allowing dispersed generators to adjust their outputs appropriately to meet the load and loss requirements of the network.

This is achieved through application of participation factors based on the generation capacity. The generator domains for substation and participating DGs and the direction of power flow have been considered in the algorithm.
RECOMMENDATION FOR FUTURE WORK

Other methods based on the conventional load flow methods i.e. Gauss-Siedel, Decoupled, Fast Decoupled load flow methods as well as other new methods with renewable energy could be included in future works for comparison purposes.
THANK YOU!