Available Transfer Capability (ATC) Calculation of a Power Network with Renewable

Major Project Report

Submitted in Partial Fulfillment of the Requirements for the

Degree of

MASTER OF TECHNOLOGY

IN

ELECTRICAL ENGINEERING

(Electrical Power Systems)

By

Smit Patel

(16MEEE19)

Department of Electrical Engineering

INSTITUTE OF TECHNOLOGY

NIRMA UNIVERSITY

AHMEDABAD-382481

May 2018

Undertaking for originality of the work

I **Patel Smit Kiritbhai** roll no. **(16MEEE19)**, give undertaking that the major project entitled **"Available Transfer Capability (ATC) Calculation of a Power Network with Renewable"** submitted by me, towards the partial fulfillment of the requirement for the degree of Master of technology in Electrical Power Systems of Nirma University, Ahmedabad, is the original work carried out by me and I give assurance that no attempt of plagiarism has been made. I understand that in the event of any similarity found subsequently with any published work or any dissertation work elsewhere; it will result in serve disciplinary action.

____

Signature of Student

Date:

Place: Ahmedabad

Endorsed by:

____

Project Supervisor
Dr. Akhilesh Nimje
Associate Professor
Department of Electrical Engineering
Institute of Technology
Nirma University
Ahmedabad

CERTIFICATE

This is to certify that the Major Project Report entitled **"Available Transfer Capability (ATC) Calculation of a Power Network with Renewable"** submitted by **Mr. Patel Smit Kiritbhai (16MEEE19)**, towards the partial fulfillment of the requirements for the award of degree in Master of Technology (Electrical Engineering) in the field of Electrical Power Systems of Nirma University is the record of work carried out by him under our supervision and guidance. The work submitted has in our opinion reached a level required for being accepted for examination. The results embodied in this major project work to the best of our knowledge have not been submitted to any other University or Institution for award of any degree or diploma.

Project Guide
Dr. Akhilesh Nimje
Associate Professor
Department of Electrical Engineering
Institute of Technology
Nirma University
Ahmedabad

Head of Department
Department of Electrical Engineering
Institute of Technology
Nirma University
Ahmedabad

Director
Institute of Technology
Nirma University
Ahmedabad

Acknowledgement

I would first of all like to thank **Dr. Akhilesh Nimje** and Prof. **Chintan D. Patel** Assistant Professor, Department of Electrical Engineering, Institute of Technology Nirma University, at Ahmedabad whose keen interest and excellent knowledge base helped me to carry out the dissertation work. His constant support and interest in the subject equipped me with a great understanding of different aspects of the project work.

I further extend my thanks to **Dr. P. N. Tekwani** , Head of the Department of Electrical Engineering, Institute of Technology, Nirma University, Ahmedabad and Dr. Alka Mahajan , Director, Institute of Technology, Nirma University, Ahmedabad for providing all kind of required resources during my study.

Although, this dissertation has just my name on it, many friends and colleagues have contributed to the completion of this dissertation, both directly, by helping me throughout my studies. I am highly indebted to Almighty and my family member by whose blessings, endless love and support, helped me to complete my study and encouraged me in all possible way.

- Patel Smit Kiritbhai

16MEEE19

Abstract

Electric utility around the world is undergoing restructuring, deregulation and privatization. Hence transmission network tend to be heavily loaded and transmission services become one of the most critical element. Power system transfer capability indicates how much inter area power transfers can be increased without compromising system security. For both planning and operation of the bulk power market, accurate identification of this capability is very important. Available Transfer Capacity (ATC) is the amount of transfer capacity that is available at a certain time in the electric power network under different system operating conditions. The computation of ATC is very important to keep reliability and security of power system. An accurate ATC computation is also very important for strengthening of the transmission system. If the computed ATC is less than the ATC of the system, the transmission of power will not be efficient and economic, if the computed ATC is more than the ATC of the system, the transmission line will be operating at dangerous state and any further power increase may result in collapse the whole system and the result of that is disastrous. The value of ATC for a transmission line will vary with many cases with the consideration of size of the system required to be evaluated, computation time frame, storage requirement etc. It is preferable to determine ATC using consideration of PTDF(power transfer distribution factor). For the purpose of determination of ATC of any typical power network, DCPTDF(DC Power Transfer Distribution Factors) method is considered as preferable. Hence, mathematical modeling of IEEE 6 bus and WSCC 9 bus system is carried out in MATLAB . The algorithm of DCPTDF calculations have been implemented for the said system using program in MATLAB. To validate the result using MATLAB, same system is developed in Powerworld Simulator education evalution 19 version and Powerworld Simulator 17 GSO education edition version and using the same approve DCPTDF have been analyzed and compared. This project also focuses on the variation of ATC value with varying renewable energy.

Abbreviations

ATC	Available Transfer Capability
TTC	Total Transfer Capability
TRM	Transmission Reliability Margin
CBM	Capacity Benefit Margin
CPF	Continuation Power Flow Method
OPF	Optimal Power Flow Method
DCPTDF	DC Power Transfer Distribution Factors
ACPTDF	AC Power Transfer Distribution Factors
LODF	Line Outage Distribution Factor
GSF	Generation Shift Factor

Contents

List of Figures

List of Tables

Chapter 1

Literature Survey

In last few years, transfer of bulk electrical power over long distances has increased in order to have a reliable and economical electrical supply. In this paper, available transfer capability method AC & DC power transfer distribution factor, CPF and repeated AC power flow used. The method was tested on IEEE6 bus & IEEE39 bus system. IEEE6 bus result with ATC value between buses 2-3 & buses 1-5. IEEE39 bus comparison of ATC value between buses 32-39 & buses 36-38[1].

The paper presents an iterative method for transmission capability determination. Proposed method uses the sensitivity of Newton-Raphson Jacobin matrix. It does not require sequential solution of power flow making ATC determination faster. In this paper, flow chart is used for the proposed method. It compares AC & DC PTDF, proposed method, repeated ACLF Method on IEEE6 bus & IEEE39 bus system[2].

The paper uses the combination of the rated path system and probabilistic method to calculate ATC with wind power generation. Modified load flow program & the Newton-Raphson load flow has been employed in this method. The thermal limit of transmission line, upper and lower limit voltage is to be considered. The results shows that the proposed method is used for practical system and is able to determine ATC limited by thermal as well as bus voltage limit[3].

Available transfer capability(ATC) calculation method used for test system is mentioned from NPTEL course referred to power systems. The MATLAB code is developed from mentioned algorithm and theory base. Hence, generalized structure of code can be formulated. DCPTDF method is used to develop a generalize code for Available Transfer Capability (ATC) calculation of a power network with renewable. IEEE6 bus & IEEE39 bus systems have been developed in MATLAB 2015[4].

The paper gives introduction about transmission reliability margin, capacity benefit margin and available transfer capability. The additional amount of power that can be transferred through the network over and above already committed is used without any violation of limits is called available transfer capability[5].

The book give introduction part and different method for calculation of available transfer capability for most of system.and give defination about different terms[6].
Here in this paper IEEE 30 bus system branch data and generation data taken for this paper[7].
Here in this article IEEE 39 bus new England system branch data and generation data taken from this work in powerworld simulator and matlab[8]. GSF(Generation Shift Factor) equation and theory avialable in this book [9] [10].

Objective

Determination of Available Transfer Capability (ATC) for power network including renewable energy with different seller and buyer.

Scope of Work

Investigation for impact of uncertain nature influenced by renewable energy sources on ATC of power network.

Methodology to be Adopted

i) Study and literature review for different network of determining Available transfer capability(ATC).

ii) Selection of suitable method of ATC.

iii) Development of MATLAB code for determination of ATC using DCPTDF method.

iv) Validation of developed matlab code by simulation of same scenario and system in powerworld simulator.

v) Included of renewable energy sources and determination of ATC for the same.

Chapter 2

Introduction of ATC

2.1 Background

- The inter-area tie lines are designed to address the reliability, system security and system restoration. Inter-area tie lines are the means of bulk power transfers on a regular basis from sources of economic generation to loads. In other words, due to deregulation, the paradigm of grid integration has shifted from regional self-sufficiency to optimal utilization of resources across large geographical areas. Thus, it becomes imperative on the part of system operator to quantify the Available Transfer Capability (ATC) of the network and allocate the same to the market participants in an efficient manner.

- Calculation of ATC gains a lot of importance under such market structures. In early days of deregulation in USA, the ATC values for the next hour and for each hour into the future would be placed on a website known as the open access same-time information system (OASIS), to be operated by the ISO.

- To send a power transaction on the ISO's transmission system would access OASIS(Open Access Same-time Information System) web pages and use the ATC information available there to determine if the transmission system could accommodate the transaction and to reserve the necessary transmission service.

- The difference between **transmission capacity** and **transfer capability**

2.1.1 Transmission Capacity

The capacity specifically mentions the rating of the equipment example - the ampacity of the conductor.
Ampacity= maximum amount of electric current in conductor.

2.1.2 Transfer Capability

The capability depends upon generation, customer demand and the conditions in a transmission system for the given time period.
Thus, the capacity of a circuit may not change much from time to time.
However, the capability always changes with the time by virtue of changes in the system condition.

2.2 Definition of Various Terms

2.2.1 Available Transfer Capability (ATC)

It is a measure of the transfer capability remaining in the physical transmission network for further commercial activity over and above already committed uses. Mathematically, ATC is defined as the Total Transfer Capability (TTC) less the Transmission Reliability Margin (TRM), less the sum of existing transmission commitments (which includes retail customer service) and The Capacity Benefit Margin(CBM)
ATC = TTC - TRM - Existing Transmission Commitments (including CBM)

2.2.2 Total Transfer Capability (TTC)

It is defined as the amount of electric power that can be transferred over the interconnected transmission network in a reliable manner while meeting all of the specific set of defined pre and post contingency system conditions.

2.2.3 Transmission Reliability Margin (TRM)

It is defined as the amount of transmission transfer capability necessary to ensure that the interconnected transmission network is secure under a reasonable range of uncertainties in system conditions.

2.2.4 Capacity Benefit Margin (CBM)

It is defined as the amount of transmission transfer capability reserved by load serving entities to ensure that the interconnected systems do meet generation reliability requirements.

2.3 Limits for Transfer Capability

1. Thermal Limits
2. Voltage Limits
3. Stability Limits

1. Thermal Limits

   Thermal limits establish the maximum amount of electrical current that a transmission line or electrical facility can conduct over a specified time period before it sustains permanent damage by overheating.

2. Voltage Limits

   System voltages and changes in voltages must be maintained within the range of acceptable minimum and maximum limits.

3. Stability Limits

   The transmission network must be capable of surviving disturbances through the transient and dynamic time periods following the disturbance.

   TTC = Minimum of (Thermal Limit, Voltage Limit, Stability Limit)

2.4 Method for ATC Calculation

1. Continuation Power Flow method (CPF)
2. Optimal Power Flow method (OPF)
3. Repeated Power Flow method (RPF)
4. Sensitivity based power flow method

1. Continuation Power Flow method (CPF)

   Continuation Power Flow (CPF) is first introduced for determining the maximum load ability. CPF method is based on full AC power flow solution to incorporate the effects of reactive power flows, voltage limits and voltage collapse as well as thermal loading effects. But the use of CPF in determining ATC is complex and the computational time increases when the contingency analyses are introduced for all possible cases. Consequently, it is not suitable for on-line applications in its present form.

   The CPF algorithm effectively increases the controlling parameter in discrete steps and solves the resulting power flow problem at each step. The procedure is continued until a given condition or physical limit preventing further increase is reached. Hence, the speed of proposed method is very slow. Consequently, it is not suitable for online applications in its present form. So this method is time consuming.

2. Optimal Power Flow method (OPF)

   The main idea is to formulate an optimization problem such that the dominant elements are the equality and inequality constraints of power flow. But solution of optimization problem for large systems becomes very time consuming and hence this approach cannot be applied in real- time for large systems. OPF methods are widely used to determine ATC in power corridors of the system.

   However these optimization methods are suitable in case of open access system where there is a possibility of power transactions occurring from any point to any point.

3. Repeated Power Flow method (RPF)

   This approach starts from a base case and repeatedly solves the power flow equations each time increasing the power transfer by a small increment until an operation limit is reached. The advantage of this approach is its simple implementation and the ease to take security constraints into consideration but takes long time for iteration.

4. Sensitivity based power flow method

   (a) DC Power Transfer Distribution Factors (DCPTDF)

   (b) AC Power Transfer Distribution Factors (ACPTDF)

   (a) DC Power Transfer Distribution Factors (DCPTDF)
   DC power transfer distribution factors (DCPTDF) based method is reported for fast calculation of ATC. But this method has a poor accuracy when X/R ratio is low due to assumptions involved. This is very useful due to its simplicity in calculation and speedy outcomes. The DC power flow methods take into consideration only the thermal limits.

   (b) AC Power Transfer Distribution Factors (ACPTDF)
   These sensitivity factors are based on linear incremental power flow, which are very simple to define and calculate . In ACPTDF method, a sequential full ac power flow is not required and hence has a high calculation speed. The AC Optimal Power Flow (OPF) methods consider thermal as well as voltage limits.

   CPF and OPF based methods are accurate but very time consuming, especially for large systems . Among the existing methods of ATC calculation, PTDF based methods are fastest.

2.5 DC Load Flow Model

Following are the assumptions when DC model is employed instead of AC model:

- Voltage magnitudes are constant.
- Only angles of complex bus voltages vary.
- The variation in angle is small.
- Transmission lines are lossless.

These assumptions create a model that is a reasonable first approximation for the real power system, which is only slightly nonlinear in normal steady state operation. The model has advantages for speed of computation, and also has some useful properties like linearity and superposition.

With these assumptions, power flows over transmission lines connecting bus i and bus j is given as:

$$P_{lm} = \frac{1}{X_{lm}}(\theta_l - \theta_m) \tag{2.1}$$

Where,

X_{lm} line inductive reactance in per unit

θ_l phase angle at bus l

θ_m phase angle at bus m

The total power flowing into the bus i, P_i is the algebraic sum of generation and load at the bus and is called a bus power injection. Thus,

$$P_i = \sum_j P_{ij} = \sum_j \frac{1}{X_{ij}}(\theta_i - \theta_j) \tag{2.2}$$

This can be expressed in a matrix form as:

$$\begin{bmatrix} P_l \\ M \\ P_n \end{bmatrix} = [B_X] \begin{bmatrix} \theta_l \\ M \\ \theta_n \end{bmatrix} \tag{2.3}$$

Where, the elements of the susceptance matrix B_X are functions of line reactances . One node is assigned as a reference node by making its angle zero and deleting corresponding row and column in [B$_X$]$matrix.Thus$,

$$[X_{init}] = [B_{X,reduced}]^{-1} \tag{2.4}$$

The dimension $[X_{init}]$of obtained is $(n - 1 \times n - 1)$. Let us augment it by adding zero column and row corresponding to reference bus. The angles in equation (2.3) can be found out as

$$\begin{bmatrix} \theta_l \\ M \\ \theta_n \end{bmatrix} = [X] \begin{bmatrix} P_l \\ M \\ P_n \end{bmatrix} \tag{2.5}$$

Thus, power flow over line lm can be found out using equation (2.1).

2.6 Power Transfer Distribution Factor (PTDF)

The power transfer point of view, a transaction is a specific amount of power that is injected into the system at one bus by a generator and drawn at another bus by a load. The coefficient of linear relationship between the amount of a transaction and flow on a line is represented by PTDF. It is also called sensitivity because it relates the amount of one change - transaction amount - to another change - line power flow.

PTDF is the fraction of amount of a transaction from one bus to another that flows over a transmission line. $PTDF_{lm,ij}$ is the fraction of a transaction from bus i to bus j that flows over a transmission line connecting buses l and m.

$$PTDF_{lm,ij} = \frac{\Delta P_{lm}}{P_{ij}} \tag{2.6}$$

2.6.1 Calculation of PTDF Using DC Model

Suppose there exists only one transaction in the system. Let the transaction be of 1 MW from bus i to bus j. Then, the corresponding entries in equation (2.7) will be: $p_i = 1$ and $p_j = -1$. All other entries will be zero. From equation (2.5), we get

$$\theta_l = \begin{bmatrix} X_{l,1} & L & X_{l,n-1} \end{bmatrix} \begin{bmatrix} 0 \\ -1 \\ M \\ +1 \\ 0 \end{bmatrix} \tag{2.7}$$

$$\theta_m = \begin{bmatrix} X_{m,1} & L & X_{m,n-1} \end{bmatrix} \begin{bmatrix} 0 \\ -1 \\ M \\ +1 \\ 0 \end{bmatrix} \tag{2.8}$$

Thus,

$$\theta_l = X_{li} - X_{lj} \tag{2.9}$$

$$\theta_m = X_{mi} - X_{mj} \tag{2.10}$$

Using equations (2.9), (2.10) and (2.1), the PTDF can be calculated as

$$PTDF_{lm,ij} = \frac{X_{li} - X_{mi} - X_{lj} + X_{mj}}{x_{lm}} \tag{2.11}$$

x_{lm} Reactance of transmission line connecting buses l and m (from linedata)

X_{li} Entry lth row and ith column of the bus reactance matrix X

The change in line flow associated with a new transaction is then (from [x] matrix)

$$\Delta P_{lm} = PTDF_{lm,ij} P_{ij} \tag{2.12}$$

Where,

l and m buses at the ends of the line being monitored

i and j from and to bus numbers for the proposed new transactions

P_{ij} maximum capacity of line in MW (from linedata)

2.7 ATC Calculation Using PTDF

ATC is determined by recognizing the new flow on the line from node l to node m, due to a transaction from node i to node j. The new flow on the line is the sum of original flow P^0_{lm} and the change.

$$P_{lm} = P^0_{lm} + PTDF_{lm,ij} P_{ij} \tag{2.13}$$

Where, P^0_{lm} is the base case flow on the line and P_{ij} is the magnitude of proposed transfer. If the limit on line lm, the maximum power that can be transferred without overloading line lm,

$$P^{max}_{lm,ij} = \frac{\mathrm{P^{max}_{lm} - P^0_{lm}}}{\mathrm{PTDF_{lm,ij}}} \tag{2.14}$$

$\mathrm{P}^{max}_{lm,ij}$ is the maximum allowable transaction from node i to node j constrained by the line from node l to node m. ATC is the minimum of the maximum allowable transactions over all lines.

Using the above equation, any proposed transaction for a specific hour may be checked by calculating ATC. If it is greater than the amount of the proposed transaction, the transaction is allowed. If not, the transaction must be rejected or limited to the ATC.

$$ATC_{ij} = \min\left(P^{max}_{lm,ij}\right) \tag{2.15}$$

Using the above equation(2.15), any proposed transaction for a specific hour may be checked by calculating ATC. If it is greater than the amount of the proposed transaction, the transaction is allowed. If not, the transaction must be rejected or limited to the ATC.

2.8 Contingency Analysis

2.8.1 Line Outage Distribution Factor (LODF)

When an outage occurs, the power flowing over the outaged line is redistributed onto the remaining lines in the system. The LODF is the measure of this redistribution. $LODF_{lm,rs}$ is the fraction of the power flowing on the line rs before it is outaged, which now flows over a line from l to m.

$$\Delta P_{lm,rs} = LODF_{lm,rs}P_{rs} \tag{2.16}$$

The LODF is ,

$$LODF_{lm,rs} = \frac{x_{rs}(X_{lr} - X_{ls} - X_{mr} + X_{ms})}{x_{lm}(x_{rs} - (X_{rr} + X_{ss} - 2X_{rs})} \tag{2.17}$$

Where,

x_{lm}=reactance of line connecting bus l and m

X_{lr}=entry in lth row and rth column of bus reactance matrix X

Consider a transaction from bus i to bus j and the outage of a line (line rs). The change in flow on line rs due to the transaction is,

$$\Delta P_{rs}{}^{New} = PTDF_{rs,ij}P_{ij} \tag{2.18}$$

When line rs is outaged, part of the flow appears on line lm. s resulting from both the outage of the line rs and a new transaction from bus i to bus j is given by,

$$\Delta P_{lm,rs} = (PTDF_{lm,ij} + LODF_{lm,rs} PTDF_{rs,ij}) P_{ij} \tag{2.19}$$

The maximum contingency limited transfer from bus i to bus j, limited by line lm, with the outage of line rs is given by,

$$\Delta P^{\max}_{ij,lm,rs} = \frac{P^{\max}_{lm} - P^{0}_{lm} - (LODF_{lm,rs} * P^{0}_{rs})}{PTDF_{lm,ij} + LODF_{lm,rs} PTDF_{rs,ij}} \tag{2.20}$$

Where,

$P^{\max}_{lm}$ =indicates the post contingency flow limit on line lm.

To find the contingency limited ATC, all possible combinations of outaged lines and limiting lines must be checked, as well as steady state transfer limit.

$$ATC_{ij,rs} = \min(minP^{\max}_{ij,lm}, minP^{\max}_{ij,lm,rs}) \forall lm \tag{2.21}$$

Using the above equations(2.21), any proposed transaction for the specific hour may be checked by calculating the ATC. If it is greater than the amount of proposed transaction, the transaction is allowed. If not, then transaction must be rejected or limited to the ATC.

2.9 Reduction in Renewable Power

2.9.1 Generation Shift Factor(GSF)

When sudden reduction is occurs in the renewable system, at that time generation shift factor used that particular system.

$$GSF = \frac{X_{li} - X_{mi}}{x_{lm}} \tag{2.22}$$

Where,

X_{li} =reactance of from bus l to renewable bus i

X_{mi} =reactance of to bus m to renewable bus i

x_{lm} =reactance of line lm

The maximum contingency limited transfer from bus i to bus j, limited by line lm, with the outage of line rs,with renewable generater on i,and reduction in renewable power p' is given by,

$$\Delta P^{\max}_{ij,lm,rs} = \frac{P^{\max}_{lm} - P^0_{lm} - (LODF_{lm,rs} * P^0_{rs}) - (GSF_{lm,i} * P')}{PTDF_{lm,ij} + LODF_{lm,rs}PTDF_{rs,ij}} \tag{2.23}$$

To find the contingency limit and reduction in renewable power ATC, all possible combinations of outaged lines and limiting lines, as well as steady state transfer limit is to be checked.

$$ATC_{ij,rs} = \min(minP^{\max}_{ij,lm}, minP^{\max}_{ij,lm,rs})\forall lm \tag{2.24}$$

Using the above equations (2.22) to (2.24) the proposed transaction for the specific hour may be checked by calculating the ATC. If it is greater than the amount of proposed transaction, the transaction is allowed. If not, then transaction must be rejected or limited to the ATC.

Chapter 3

Simulation And Results

3.1 Matlab Algorithm

Step 1 :- Take the input of num of elements and nodes .

Step 2 :- Create a ybus from the linedata .

Step 3 :- From ybus create a [B] by removing 1st row and 1st columns .

Step 4 :- Calculate [X] using [X]=1/[B]

Step 5 :- Add 1st row and 1st columns having all elements zero in [X].

Step 6 :- Take the input of seller bus and buyer bus

Step 7 :- Find out [PTDF] using $PTDF_{lm,ij} = \frac{X_{li} - X_{mi} - X_{lj} + X_{mj}}{x_{lm}}$

Step 8 :- Create columns matrix [pmax] that is the thermal limits .

Step 9 :- Create [p0] (DC power flow) for that using [ybus] in there remove 1st row and 1st columns then [zbus] then [mismatch]= generation power- demand power then delta=[zbus]*[mismatch] then [power]=[delta(from bus)-delta(to bus)] / line reactance [p0]=[power]

Step 10 :- Calculate [p] using $\mathrm{P}_{lm,ij}^{max} = \frac{\mathrm{P_{lm}^{max} - P_{lm}^{0}}}{\mathrm{PTDF_{lm,ij}}}$

For that if [p0] ptdf both positive or [p0] ptdf negative then p= [pmax]- [(positive)p0]/positive[ptdf] Otherwise p= [pmax]+[(positive)p0]/positive[ptdf]

Step 11 :- Calculate ATC using $\mathrm{ATC}_{ij} = \min\left(P_{lm,ij}^{max}\right)$

Step 12 :- Take a input for num of element which is in outage of line. That line stored in rs line outage.

Step 13 :- Calculate [LODF] using $LODF_{lm,rs} = \frac{x_{rs}(X_{lr} - X_{ls} - X_{mr} + X_{ms})}{x_{lm}(x_{rs} - (X_{rr} + X_{ss} - 2X_{rs})}$

Step 14 $: - Calculate[plineout]using$

$\Delta P^{\max}_{ij,lm,rs} = \frac{P^{\max}_{lm} - P^{0}_{lm} - (LODF_{lm,rs} * P^{0}_{rs})}{PTDF_{lm,ij} + LODF_{lm,rs} PTDF_{rs,ij}}$

For that if [p0]+[LODF]*P0 PTDF+LODF*PTDF both positive or [p0]+[LODF]*P0 PTDF+LODF*PTDF negative then p=[pmax]-[[p0]+[LODF]*P0]/positive[PTDF+LODF*PTDF] Otherwise p =[pmax]+[(positive)[p0]+[LODF]*P0]/positive[PTDF+LODF*PTDF]

Step 15 :- Calculate ATC(after line outage) using,

$ATC_{ij,rs} = \min(minP^{\max}_{ij,lm}, minP^{\max}_{ij,lm,rs})\forall lm$

Step 16 :- Take a input for num of bus on which renewable added.

Step 17 :- Take a input for maximum amount of renewable power in MW

Step 18 :-calculate [GSF] using $GSF = \frac{X_{li} - X_{mi}}{x_{lm}}$

Step 19 :- Calculate [plineout] using

$$\Delta P^{\max}_{ij,lm,rs} = \frac{P^{\max}_{lm} - P^{0}_{lm} - (LODF_{lm,rs} * P^{0}_{rs}) - (GSF_{lm,i} * P')}{PTDF_{lm,ij} + LODF_{lm,rs} PTDF_{rs,ij}}$$

For that if [p0]+[LODF]*P0+[GSF]*P' PTDF+LODF*PTDF both positive or
[p0]+[LODF]*P0+[GSF]*P' & PTDF+LODF*PTDF negative then
p=[pmax]-[[p0]+[LODF]*P0+[GSF]*P']/positive[PTDF+LODF*PTDF]
Otherwise p =[pmax]+[(positive)[p0]+[LODF]*P0+[GSF]*P']/positive[PTDF+LODF*PTDF] PTDF+LODF*PTDF]

Step 20 :- Calculate ATC(after line outage) using,

$ATC_{ij,rs} = \min(minP^{\max}_{ij,lm}, minP^{\max}_{ij,lm,rs})\forall lm$

A generelized MATLAB program has been written for IEEE 6 bus, WSCC 9 bus and IEEE 30 bus, IEEE 39 bus test system. This algorithm is based on the DCPTDF method used for the calculation of the ATC in the system.

As discussed earlier, ATC value can be easily calculated form the DCPTDF method. There are several other method for calculation of ATC. DCPTDF method uses only thermal limit to be considered during the calculation on the ATC. Hence this method is prefered over other method.

If a line is opened for maintenance, the ATC is calculated when the line was connected & when it is removed. The effect of removed of a line is seen on the overloading of several other lines.

3.2 IEEE 6 Bus System in Powerworld Simulator

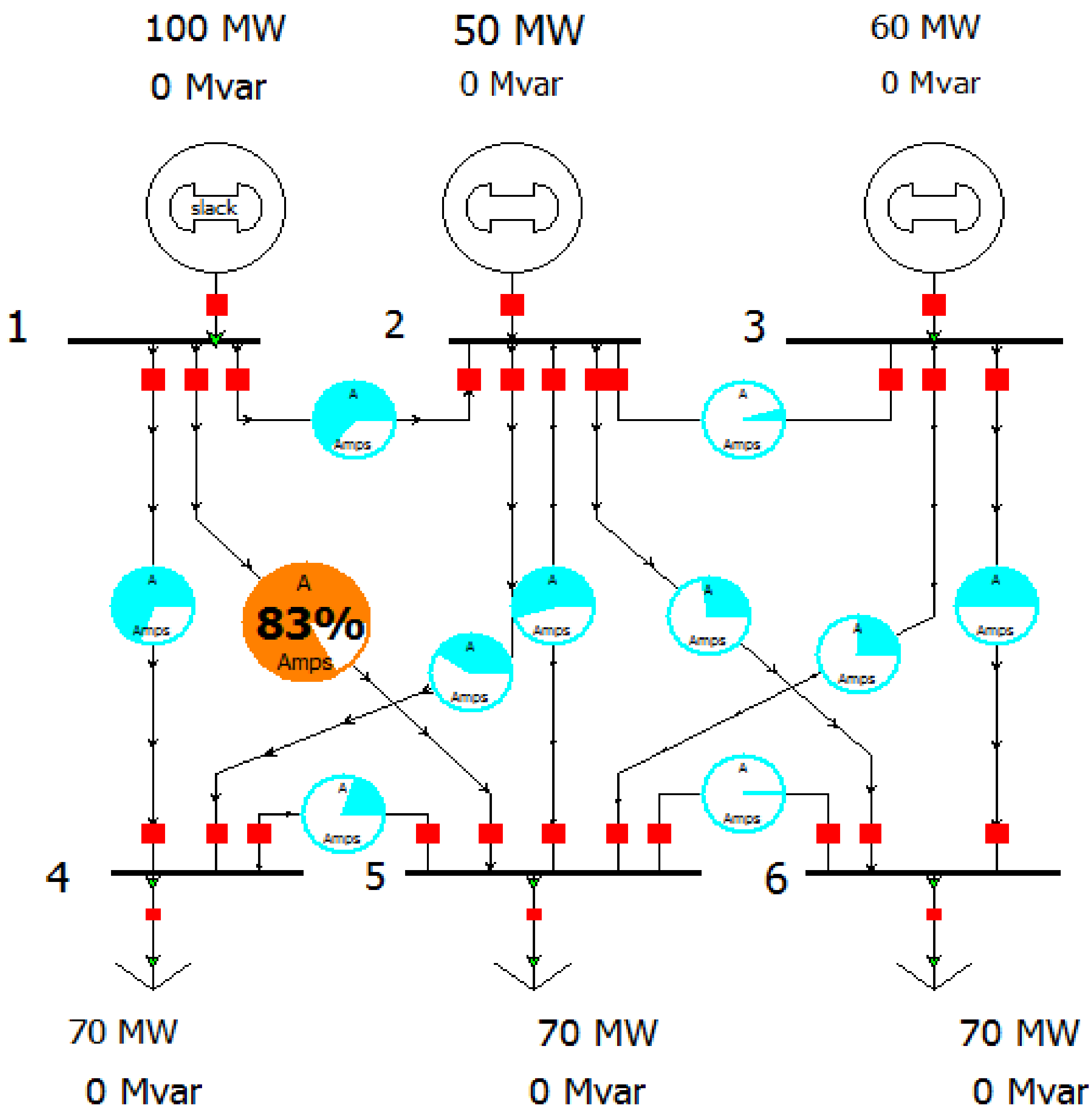
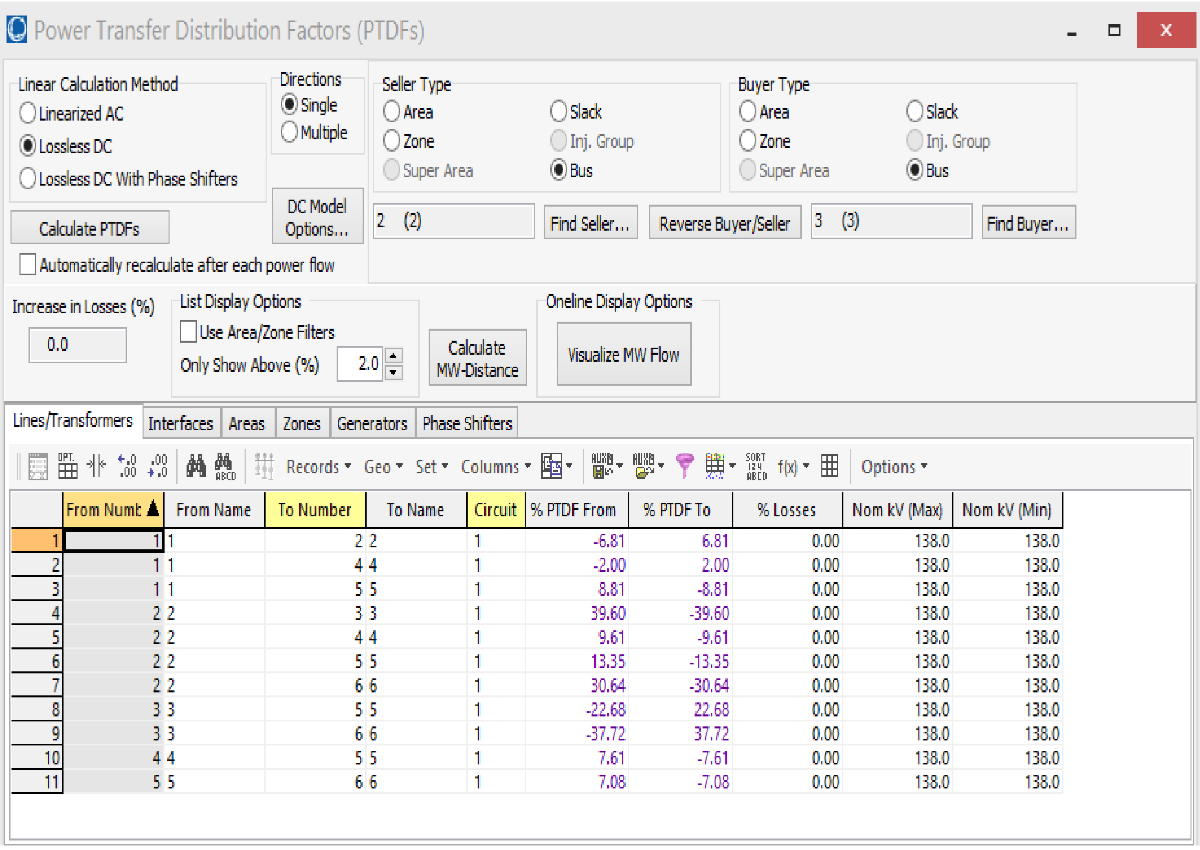


Figure 3.1: IEEE 6 Bus System in Powerworld Simulator

An IEEE 6 bus system has been simulated in Powerworld Simulator software as shown in Figure 3.1. There are three generators connected at bus 1,2 and 3. The generator connected at bus 1 is a slack generator. Generator connected at bus 2 & 3 are rated for 50 MW & 60 MW respectively.

Three loads are connected in the system at bus 4, 5 & 6 having capacity of 70 MW each.

3.3 Powerworld Simulator Results %PTDF between (2-3) Bus



	From Number	From Name	To Number	To Name	Circuit	% PTDF From	% PTDF To	% Losses	Nom kV (Max)	Nom kV (Min)
1	1	1	2	2	1	-6.81	6.81	0.00	138.0	138.0
2	1	1	4	4	1	-2.00	2.00	0.00	138.0	138.0
3	1	1	5	5	1	8.81	-8.81	0.00	138.0	138.0
4	2	2	3	3	1	39.60	-39.60	0.00	138.0	138.0
5	2	2	4	4	1	9.61	-9.61	0.00	138.0	138.0
6	2	2	5	5	1	13.35	-13.35	0.00	138.0	138.0
7	2	2	6	6	1	30.64	-30.64	0.00	138.0	138.0
8	3	3	5	5	1	-22.68	22.68	0.00	138.0	138.0
9	3	3	6	6	1	-37.72	37.72	0.00	138.0	138.0
10	4	4	5	5	1	7.61	-7.61	0.00	138.0	138.0
11	5	5	6	6	1	7.08	-7.08	0.00	138.0	138.0

Figure 3.2: IEEE 6 Bus System %PTDF Value in Powerworld Simulator between 2-3 Bus

The Figure 3.2 shows the results of PTDF values in Powerworld Simulator. When the seller bus is 2 and buyer bus is 3, the effect on all the lines in the system. It is to be noted that, the maximum PTDF value is obtained for the line connected between bus 2 and bus 3, while the minimum PTDF value is for line connetced between bus 1 and bus 2.

The PTDF value for line connected between 2 and 3 is 39.60% of its total capability. It can transfer more 60.4% power.

The PTDF value for line 1 to 4 is -2%. It shows that the power flow is taking place from bus 4 to 1. It can also allow more amount of power transfer from it.

3.4 Available Transfer Capability(ATC) Result in Powerworld Simulator between (2-3) Bus

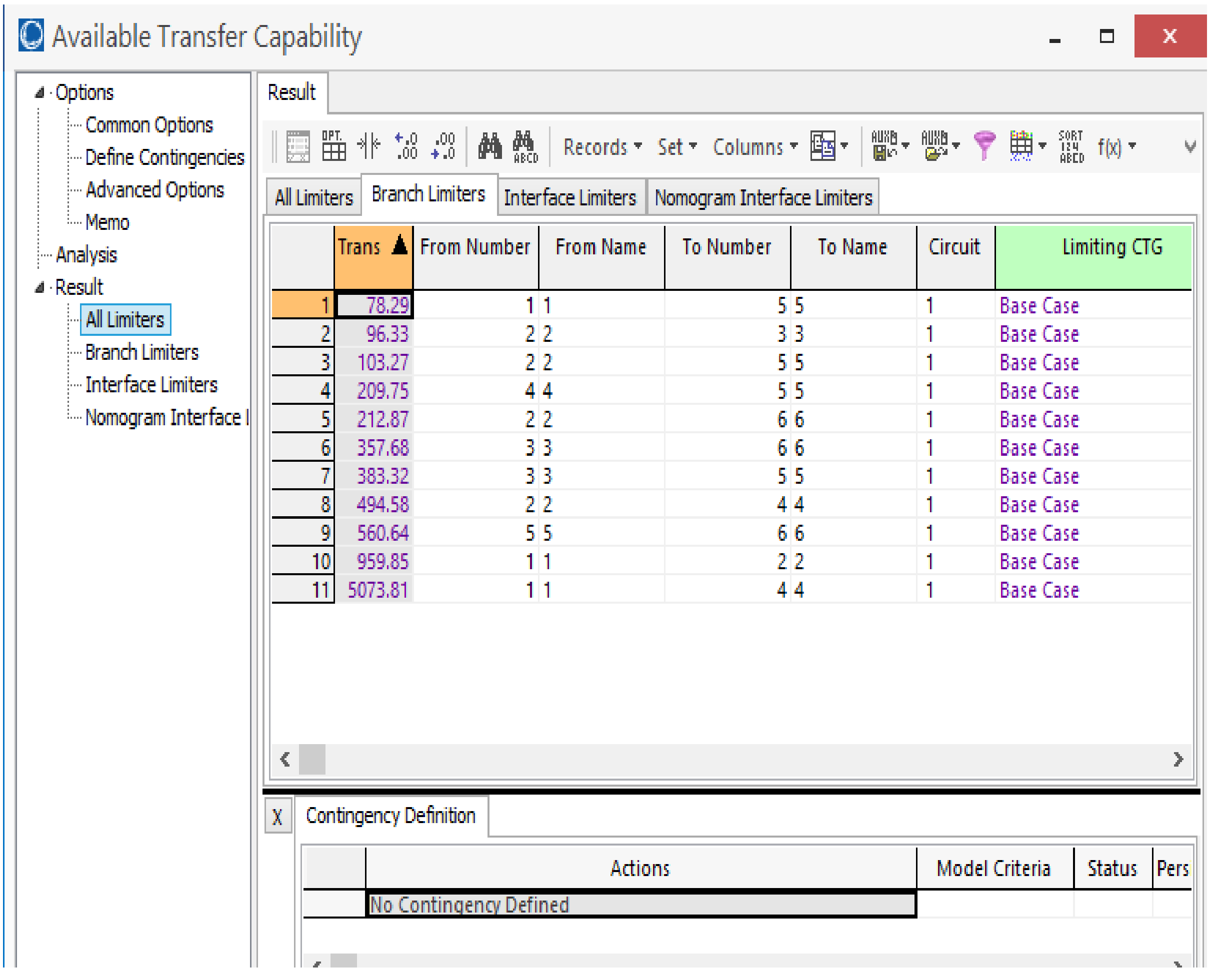


Figure 3.3: IEEE 6 Bus System ATC Value Using Powerworld Simulator between 2-3 Bus

The Figure 3.3 shows the available transfer capability of each line. When the bus 2 is seller bus and bus 3 is buyer bus. It shows that the maximum power that can be transferred from bus 3 to bus 6 is 7806.62 MW and from bus 1 to 5 is 30.15 MW. The ATC of line connected between bus 1 and bus 5 is the least among all the lines. The ATC value for the case of bus 2 as seller bus and bus 3 as buyer bus is 30.15 MW. The minimum value of ATC is chosen because if any other value higher than this is chosen, it will violate the limits of line connected between bus 1 and 5.

Table 3.1: Comparison of Powerworld Simulator Results(PTDF) and Matlab Results (PTDF) between (2-3) Bus IEEE6 Bus System

Sr no.	From bus	To bus	PTDF Value Using Powerworld Simulator (MW)	PTDF Value Using MATLAB (MW)
1	1	2	-0.0681	-0.0681
2	1	4	-0.02	-0.0200
3	1	5	0.0881	0.0881
4	2	3	0.3960	0.3960
5	2	4	0.0961	0.0961
6	2	5	0.1335	0.1335
7	2	6	0.3064	0.3064
8	3	5	-0.2268	-0.2268
9	3	6	-0.3772	-0.3772
10	4	5	0.0761	0.0761
11	5	6	0.0708	0.0708

The Table 3.1 shows the comparison between the PTDF values obtained in Powerworld Simulater and MATLAB software for bus 2 as a seller bus and bus 3 as a buyer bus. The table shows that the value of PTDF obtained in MATLAB software are matching with the PTDF values obtained in Powerworld Simulator.

Table 3.2: Comparison of Powerworld Simulator Results(ATC) and Matlab Results (ATC) between(2-3) Bus in IEEE 6 Bus System

Sr no.	From bus	To bus	ATC Value Using Powerworld Simulator (MW)	ATC Value Using MATLAB (MW)
1	1	2	959.85	959. 85
2	1	4	5073.81	5073.8
3	1	5	78.29	78. 28
4	2	3	96.33	96.328
5	2	4	494.58	494.58
6	2	5	103.27	103.26
7	2	6	212.87	212.86
8	3	5	383.32	383.31
9	3	6	357.68	357.68
10	4	5	209.75	209.74
11	5	6	560.64	560.63

The Table 3.2 shows the comparison between ATC values obtained in Powerworld Simulator and MATLAB software. It validates that the ATC obtained in MATLAB software are almost similar to that of in Powerworld Simulator. The value of ATC is the minimum value from the maximum power transfer capability of all lines. It is seen from the Table 3.2, line connected between bus 1 to 5 has ATC value of 78.29 MW calculated in Powerworls Simulator and 78.28 MW calculated in MATLAB software.

3.5 Introduction

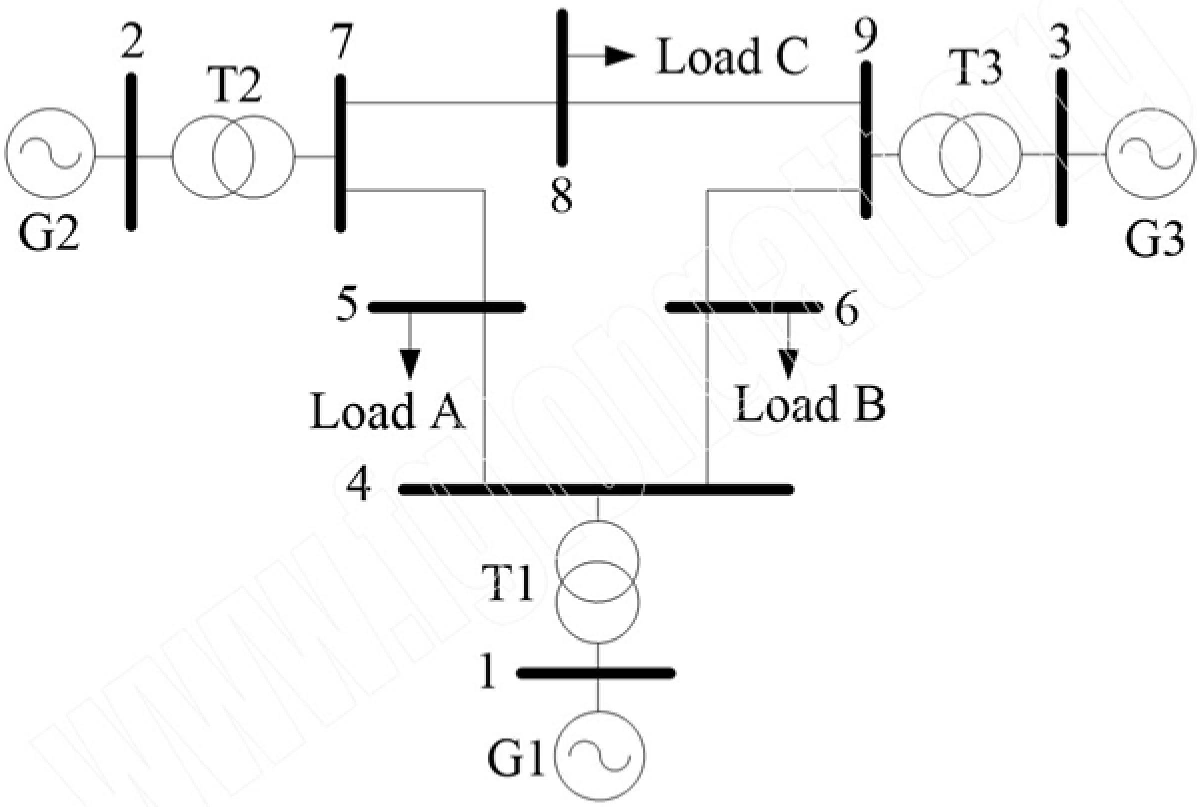


Figure 3.4: WSCC 9 Bus Sytem

Here WSCC(Western System Coordinating Council) 9 bus system one line diagram shown in Figure 3.4 [11].

3.6 Powerworld Simulator WSCC 9 Bus System

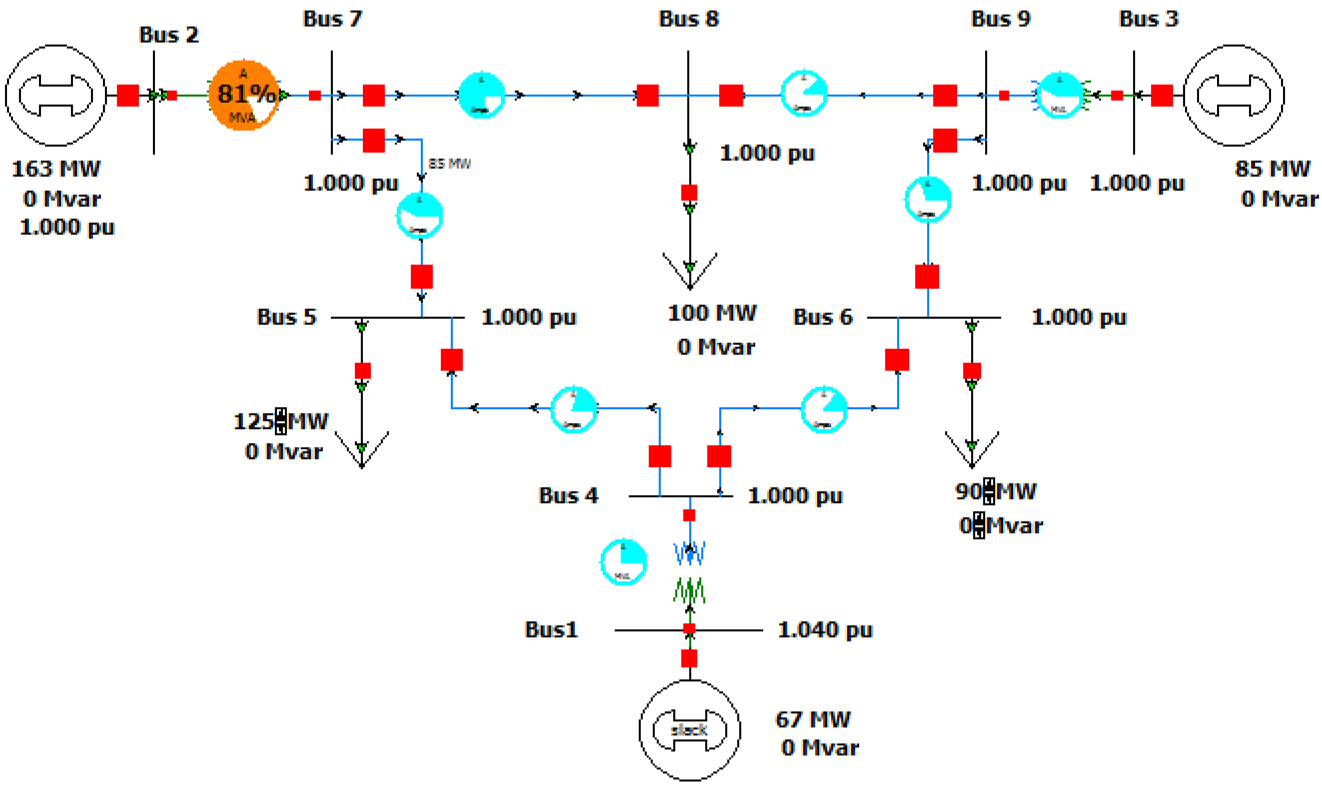
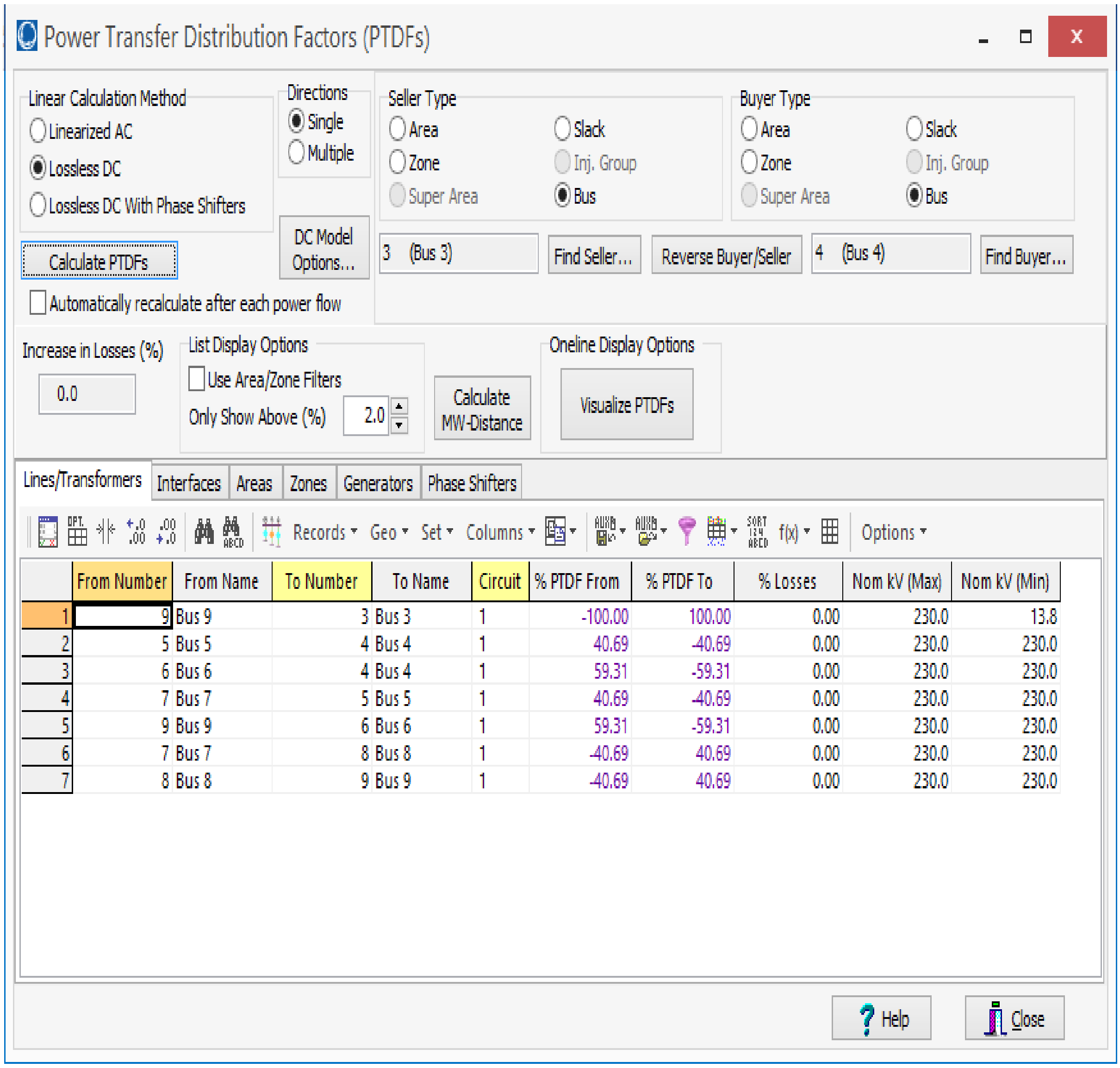


Figure 3.5: WSCC 9 Bus System in Powerworld Simulator

A WSCC 9 bus system shown in Figure 3.5 is considered for simulation purpose. This test case represents a simple approximation of the Western System Coordinating Council to an equivalent system with nine buses and three generators. Three generators are connected at bus number 1, 2 and 3. Bus 1 is considered as slack bus. The generator connected at Bus 2 and 3 have the capacity of 163 MW and 85 MW respectively. Three loads are connected in the system at bus 5, 6 and 8 having capacity of 125 MW, 90 MW and 100 MW respectively.

From Figure 3.5 there are three transformer in use. One transformer is connected between bus 1 to 4 & it is rated for 16.5/230 kV. Second transformer is connected between bus 2 to 7 & it is rated for 18/230 kV. Third transformer is connected between bus 3 to 9 & it is rated for 13.8/230 kV.

3.7 Powerworld Simulator Results %PTDF between (3-4) Bus



	From Number	From Name	To Number	To Name	Circuit	% PTDF From	% PTDF To	% Losses	Nom kV (Max)	Nom kV (Min)
1	9	Bus 9	3	Bus 3	1	-100.00	100.00	0.00	230.0	13.8
2	5	Bus 5	4	Bus 4	1	40.69	-40.69	0.00	230.0	230.0
3	6	Bus 6	4	Bus 4	1	59.31	-59.31	0.00	230.0	230.0
4	7	Bus 7	5	Bus 5	1	40.69	-40.69	0.00	230.0	230.0
5	9	Bus 9	6	Bus 6	1	59.31	-59.31	0.00	230.0	230.0
6	7	Bus 7	8	Bus 8	1	-40.69	40.69	0.00	230.0	230.0
7	8	Bus 8	9	Bus 9	1	-40.69	40.69	0.00	230.0	230.0

Figure 3.6: WSCC 9 Bus System in Powerworld Simulator %PTDF Value between 3-4 Bus

The Figure 3.6 shows the PTDF value of each line in WSCC 9 bus system for the case of bus 3 as a seller bus and bus 4 as a buyer bus. The line connected between bus 9 and bus 3 has the maximum value of PTDF. So, more power can not be allow to transfer from this line. The lines connected between bus 5 to 4, bus 7 to 8 and bus 8 to 9 have the least value of PTDF. These lines have capability to transfer more power compared to other lines.

3.8 Powerworld Simulator ATC Results between (3-4) Bus

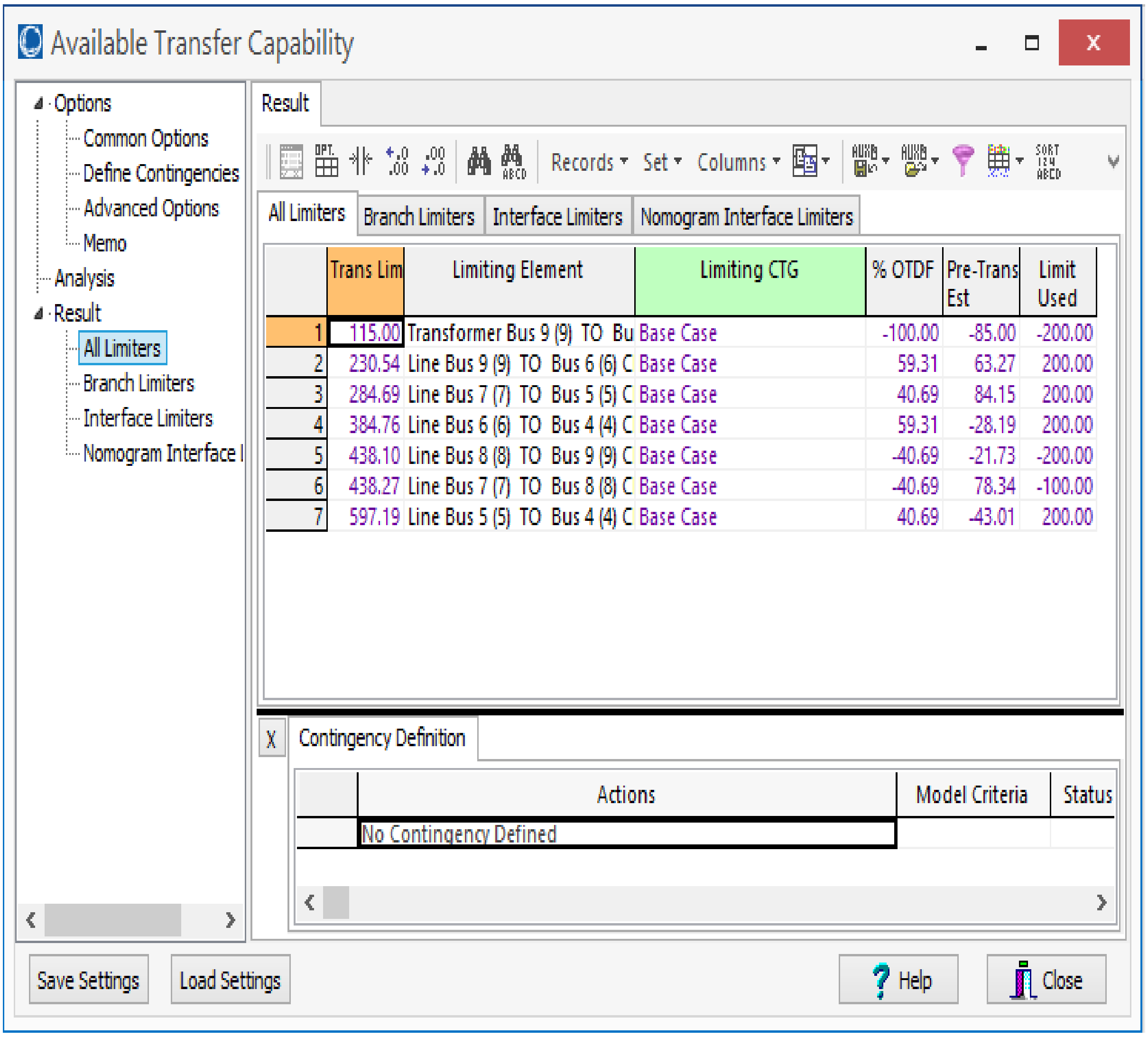


Figure 3.7: WSCC 9 Bus System in Powerworld Simulator ATC Value between 3-4 Bus

The Figure 3.7 shows the maximum power transfer capability of each line in WSCC 9 bus system when bus 3 is seleer bus and bus 4 is a buyer bus. The least value of maximum transfer capability of the lines, gives the ATC value between seller bus 3 and buyer bus 4.

The Table 3.3 shows a comparison between the PTDF value of each line for seller bus 3 and buyer bus 4 in Powerworld Simulator and MATLAB. The table varifies that the PTDF values obtained from both the software are almost equal.

Table 3.3: Comparison of Powerworld Simulator and Matlab PTDF Results between 3-4 Bus

Sr no.	From bus	To bus	PTDF Value Using Powerworld Simulator (MW)	PTDF Value Using MATLAB (MW)
1	4	1	0	0
2	2	7	0	0
3	9	3	-1.00	-1.00
4	5	4	0.4069	0.4034
5	6	4	0.5931	0.5966
6	7	5	0.4069	0.4034
7	9	6	0.5931	0.5966
8	7	8	-0.4069	-0.4034
9	8	9	-0.4069	-0.4034

The PTDF of line connected between bus 9 to 3 is -100% its shows 100% power transfer takes place from bus 3 to 9. So, it is not able to transfer more power as it is already transferring the maximum power.

Table 3.4: Comparison of Powerworld Simulator and Matlab ATC Results between 3-4 Bus

Sr no.	From bus	To bus	ATC Value Using Powerworld Simulator (MW)	ATC Value Using MATLAB (MW)
1	9	3	115.00	115.0000
2	5	4	597.19	596.6405
3	6	4	384.76	379.3237
4	7	5	284.69	286.8122
5	9	6	230.54	228.4564
6	7	8	438.27	442.9656
7	8	9	438.10	442.9656

The Table 3.4 shows a comparison between the ATC value of each line in WSCC 9 bus system when bus 3 is a seller bus and bus 4 is a buyer bus calculated in Powerworld Simulated and MATLAB software.

The infinite value of ATC for lines connected between bus 4 to 1 and for between bus 2 to 7 indicates that these two lines are not taken into consideration when bus 3 is seller bus and bus 4 is a buyer bus. For this case, the value of ATC is 115 MW. IF the value of ATC is considered to be higher than 115 MW the line limits of line connected between bus 9 and 3 will be violated. So, the value of ATC is considered to be 115 MW as it is least value of maximum power transfer capability among all the lines.

3.9 Powerworld Simulator IEEE 30 Bus System

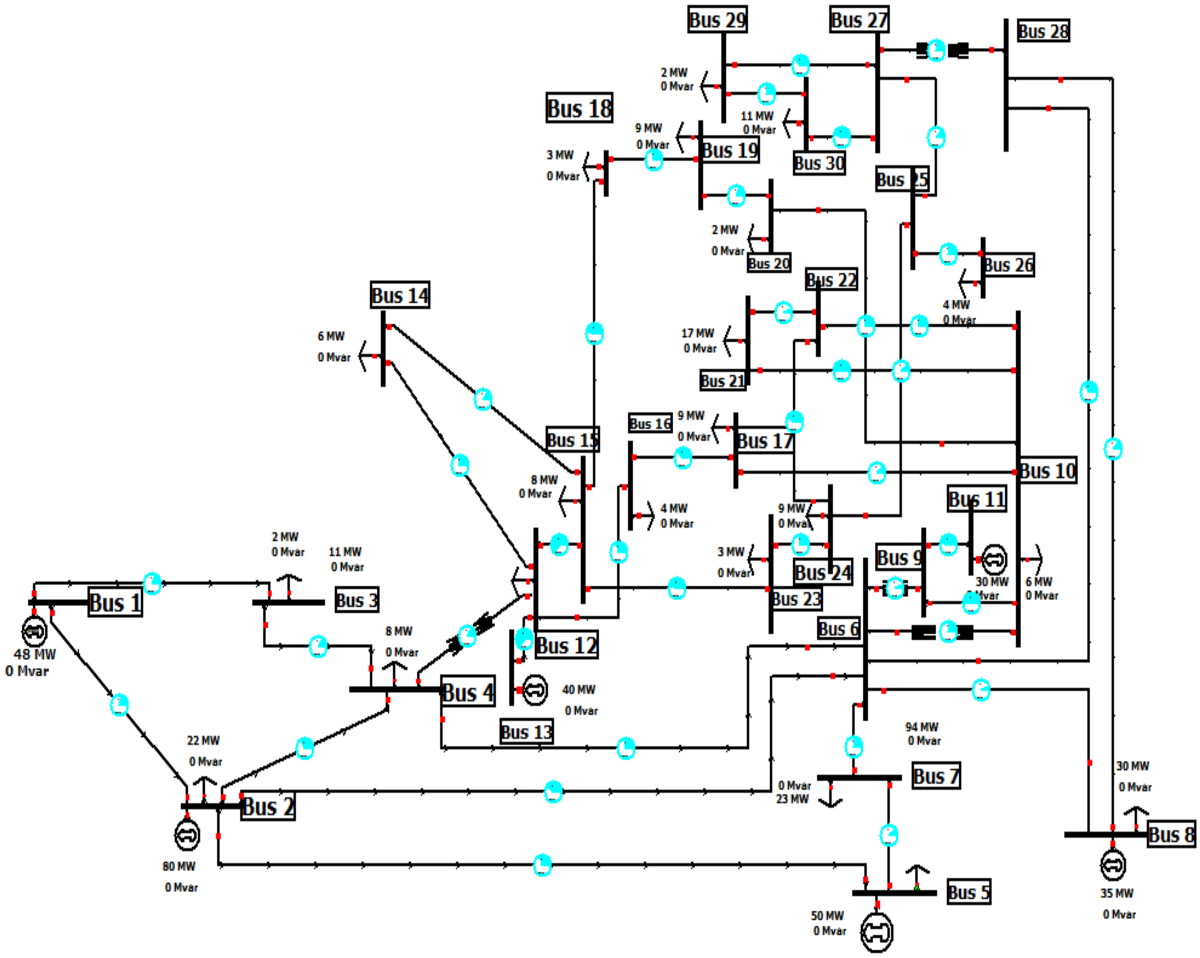


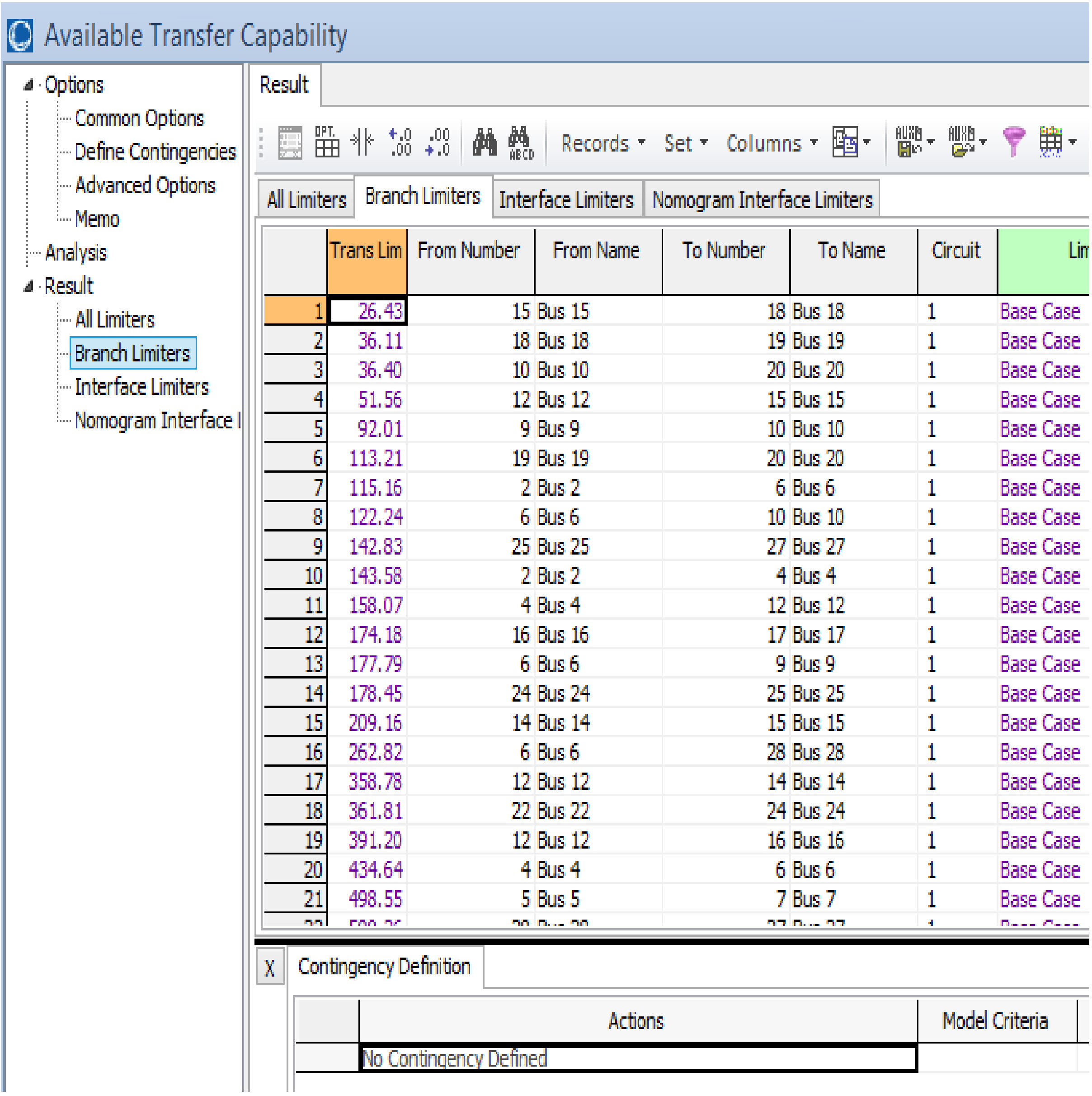
Figure 3.8: IEEE 30 Bus System in Powerworld Simulator

The Figure 3.8 shows an IEEE 30 bus system simulated in Powerworld Simulator software. These are 6 generator in this system connected at bus 1, 2, 5, 8, 11 and 13 respectively having generation capability 200, 80, 50, 35, 30 & 40 MW respectively. The generator connected at bus 1 is a swing generator.

The loads are connected at bus 2, 3, 4, 5, 7, 8, 10, 12, 14, 15, 16, 17, 18, 19, 20, 21, 23, 24, 26, 29 & 30 having capacity of 21.7, 3.4, 7.6, 94.2, 22.8, 30, 5.8, 11.2, 6.2, 8.2, 3.5, 9, 3.2, 9.5, 2.2, 17.5, 3.2, 8.7, 3.5, 2.4 and 10.6 MW respectively. The transformers are connected between bus 4 to 12, 6 to 9, 6 to 10 and 28 to 27 having voltage rating of 132/33 kV, 132/1 kV, 132/33 kV & 132/33 kV respectively. The simulation for Figure

3.8 has been done in powerworld simulator 17 GSO education edition version is 17.

3.9.1 Powerworld Simulator ATC Results between (2-20) Bus for Base case

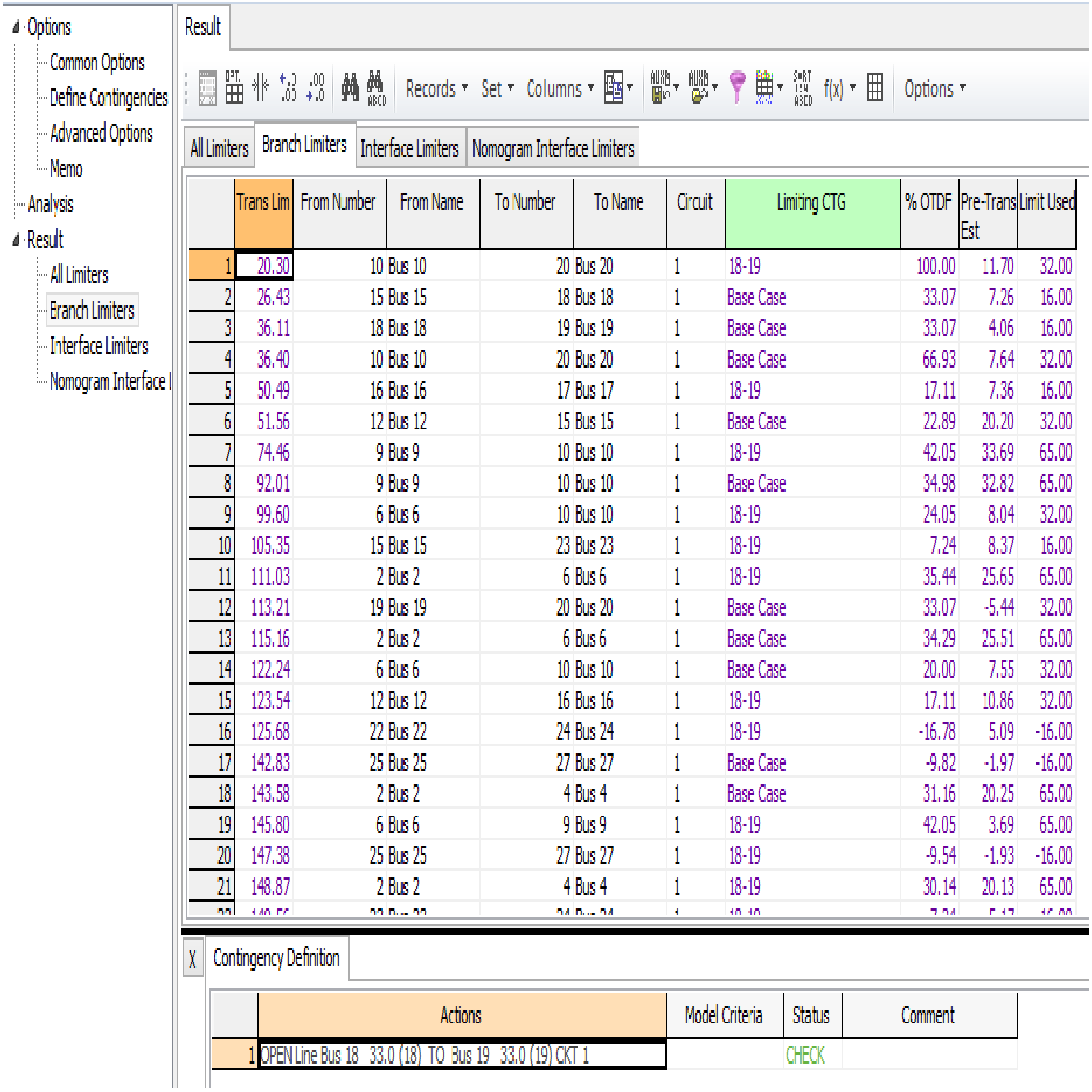


	Trans Lim	From Number	From Name	To Number	To Name	Circuit	Lim
1	26.43	15	Bus 15	18	Bus 18	1	Base Case
2	36.11	18	Bus 18	19	Bus 19	1	Base Case
3	36.40	10	Bus 10	20	Bus 20	1	Base Case
4	51.56	12	Bus 12	15	Bus 15	1	Base Case
5	92.01	9	Bus 9	10	Bus 10	1	Base Case
6	113.21	19	Bus 19	20	Bus 20	1	Base Case
7	115.16	2	Bus 2	6	Bus 6	1	Base Case
8	122.24	6	Bus 6	10	Bus 10	1	Base Case
9	142.83	25	Bus 25	27	Bus 27	1	Base Case
10	143.58	2	Bus 2	4	Bus 4	1	Base Case
11	158.07	4	Bus 4	12	Bus 12	1	Base Case
12	174.18	16	Bus 16	17	Bus 17	1	Base Case
13	177.79	6	Bus 6	9	Bus 9	1	Base Case
14	178.45	24	Bus 24	25	Bus 25	1	Base Case
15	209.16	14	Bus 14	15	Bus 15	1	Base Case
16	262.82	6	Bus 6	28	Bus 28	1	Base Case
17	358.78	12	Bus 12	14	Bus 14	1	Base Case
18	361.81	22	Bus 22	24	Bus 24	1	Base Case
19	391.20	12	Bus 12	16	Bus 16	1	Base Case
20	434.64	4	Bus 4	6	Bus 6	1	Base Case
21	498.55	5	Bus 5	7	Bus 7	1	Base Case

Figure 3.9: IEEE 30 Bus System in Powerworld Simulator ATC Value before Contingency

The Figure 3.9 shows the maximum transfer capability of each line in IEEE 30 bus system when bus 2 is seller bus & bus 20 is buyer bus. The line connected between bus 18 and 18 has least maximum transfer capability compared to other lines in the system. Thus, the ATC value for 2 as a seller bus and 20 as a buyer bus is 26.43 MW. If the higher amount of power is considered the capability of the line between 15 to 18 gets violated.

3.9.2 Powerworld Simulator ATC Results between (2-20) Bus after Line Outage (Contingency) between (18-19) Bus



	Trans Lim	From Number	From Name	To Number	To Name	Circuit	Limiting CTG	% OTDF	Pre-Trans Est	Limit Used
1	20.30	10	Bus 10	20	Bus 20	1	18-19	100.00	11.70	32.00
2	26.43	15	Bus 15	18	Bus 18	1	Base Case	33.07	7.26	16.00
3	36.11	18	Bus 18	19	Bus 19	1	Base Case	33.07	4.06	16.00
4	36.40	10	Bus 10	20	Bus 20	1	Base Case	66.93	7.64	32.00
5	50.49	16	Bus 16	17	Bus 17	1	18-19	17.11	7.36	16.00
6	51.56	12	Bus 12	15	Bus 15	1	Base Case	22.89	20.20	32.00
7	74.46	9	Bus 9	10	Bus 10	1	18-19	42.05	33.69	65.00
8	92.01	9	Bus 9	10	Bus 10	1	Base Case	34.98	32.82	65.00
9	99.60	6	Bus 6	10	Bus 10	1	18-19	24.05	8.04	32.00
10	105.35	15	Bus 15	23	Bus 23	1	18-19	7.24	8.37	16.00
11	111.03	2	Bus 2	6	Bus 6	1	18-19	35.44	25.65	65.00
12	113.21	19	Bus 19	20	Bus 20	1	Base Case	33.07	-5.44	32.00
13	115.16	2	Bus 2	6	Bus 6	1	Base Case	34.29	25.51	65.00
14	122.24	6	Bus 6	10	Bus 10	1	Base Case	20.00	7.55	32.00
15	123.54	12	Bus 12	16	Bus 16	1	18-19	17.11	10.86	32.00
16	125.68	22	Bus 22	24	Bus 24	1	18-19	-16.78	5.09	-16.00
17	142.83	25	Bus 25	27	Bus 27	1	Base Case	-9.82	-1.97	-16.00
18	143.58	2	Bus 2	4	Bus 4	1	Base Case	31.16	20.25	65.00
19	145.80	6	Bus 6	9	Bus 9	1	18-19	42.05	3.69	65.00
20	147.38	25	Bus 25	27	Bus 27	1	18-19	-9.54	-1.93	-16.00
21	148.87	2	Bus 2	4	Bus 4	1	18-19	30.14	20.13	65.00

	Actions	Model Criteria	Status	Comment
1	OPEN Line Bus 18 33.0 (18) TO Bus 19 33.0 (19) CKT 1		CHECK	

Figure 3.10: IEEE 30 Bus System in Powerworld Simulator ATC Value after Contingency

The Figure 3.10 gives maximum transfer capability for each line in IEEE 30 bus system when bus 2 is seller bus and bus 20 is buyer bus and also a contingency case is considered where the line between buses 18 and 19 gives out of service. Here, the ATC value of each line gets changed. In this case, the line connected between bus 10 to 20 has least maximum transfer capability. The ATC value for this case is 20.30 MW.

Table 3.5: Comparison of Powerworld Simulator and Matlab ATC Results between 2-20 Bus

DCPTDF Method	ATC Value Using Powerworld Simulator (MW)	ATC Value Using MATLAB (MW)	Limiting Factor
Base Case	26.4500	26.5590	Line 15-18
Line Out 18-19	20.3000	20.3000	Line 10-20

The Table 3.5 gives a comparison between the ATC values calculated in Powerworld Simulator software and MATLAB software. There are two cases considered in this table. The method used to find the ATC value in both the cases is DCPTDF method.

In the first case, the base case system is considered and the bus 2 is considered as a seller bus and bus 20 is considered as a buyer bus. The ATC value in this case is almost same in both the softwars. This value is 26.4500 MW in Powerworld Simulator & 26.5590 MW in MATLAB software. The limiting factor in this case is line connected between buses 15 & 18. It shows that if the ATC value is increased, the maximum transfer capability of this line gets violated.

In the second case, the seller bus is 2 and buyer bus is 20. The line connected between bus 18 & 19 is out of service in this case. Here, the ATC value calculated in both the cases are almost same. ATC value calculated in Powerworld Simulator is 20.3 MW & in MATLAB is 20.3 MW. The limiting factor is this case is line connected between bus 10 and 20. The limiting factor indicate that the line between bus 10 & 20 has maximum transfer capability of 20.3 MW.

It is to be noted that in the first case the value of ATC is higher than in the second case. It shows that if a line outage is occurred in the system, the ATC value of the system decreases. The line which is considered as a limiting factor changes in the case of line outage compared to base case system.

3.10 Powerworld Simulator IEEE 39 Bus System 10-Generator New England Test System

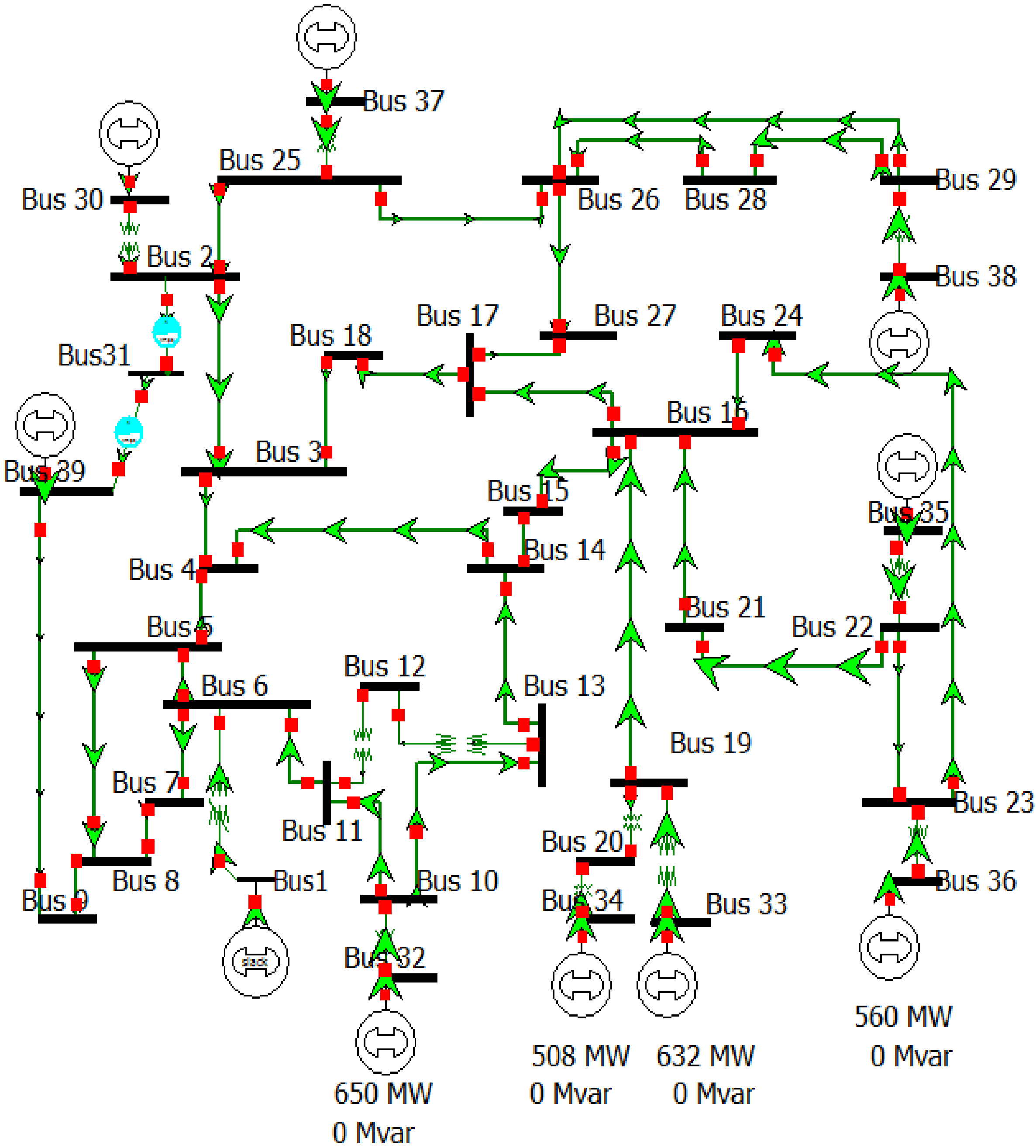
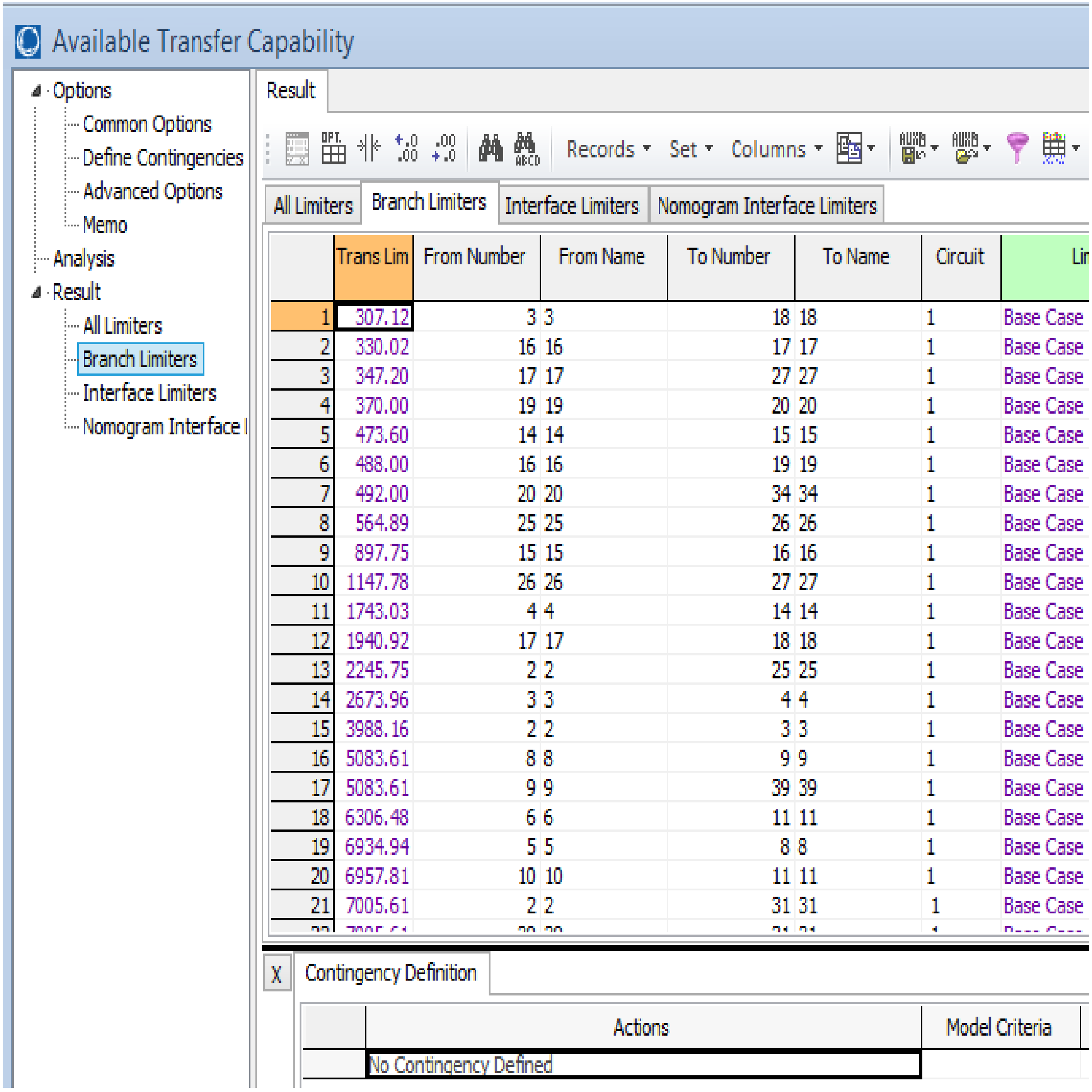


Figure 3.11: IEEE 39 Bus System 10-Generator New England Test System

The simulation for Figure 3.11 has been done in powerworld simulator 17 GSO education edition version is 17 .

3.10.1 Powerworld Simulator ATC Results between (34-26) Bus for Base Case



	Trans Lim	From Number	From Name	To Number	To Name	Circuit	Lir
1	307.12	3	3	18	18	1	Base Case
2	330.02	16	16	17	17	1	Base Case
3	347.20	17	17	27	27	1	Base Case
4	370.00	19	19	20	20	1	Base Case
5	473.60	14	14	15	15	1	Base Case
6	488.00	16	16	19	19	1	Base Case
7	492.00	20	20	34	34	1	Base Case
8	564.89	25	25	26	26	1	Base Case
9	897.75	15	15	16	16	1	Base Case
10	1147.78	26	26	27	27	1	Base Case
11	1743.03	4	4	14	14	1	Base Case
12	1940.92	17	17	18	18	1	Base Case
13	2245.75	2	2	25	25	1	Base Case
14	2673.96	3	3	4	4	1	Base Case
15	3988.16	2	2	3	3	1	Base Case
16	5083.61	8	8	9	9	1	Base Case
17	5083.61	9	9	39	39	1	Base Case
18	6306.48	6	6	11	11	1	Base Case
19	6934.94	5	5	8	8	1	Base Case
20	6957.81	10	10	11	11	1	Base Case
21	7005.61	2	2	31	31	1	Base Case

Figure 3.12: IEEE 39 Bus New England System in Powerworld Simulator ATC Value before Contingency

The Figure 3.12 shows the maximum power transfer capability of each in IEEE 39 bus New England system with consideration of bus 34 as a seller bus and bus 26 as a buyer bus. The line connected between bus 3 and 18 has the least maximum power transfer capability. So, the ATC value for this case is 307.12 MW. If the ATC value higher than this is considered, the line limits of line connected between bus 3 & 18 gets violated.

3.10.2 Powerworld Simulator ATC Results between (2-20) Bus after Line Outage (Contingency) between (18-3) Bus

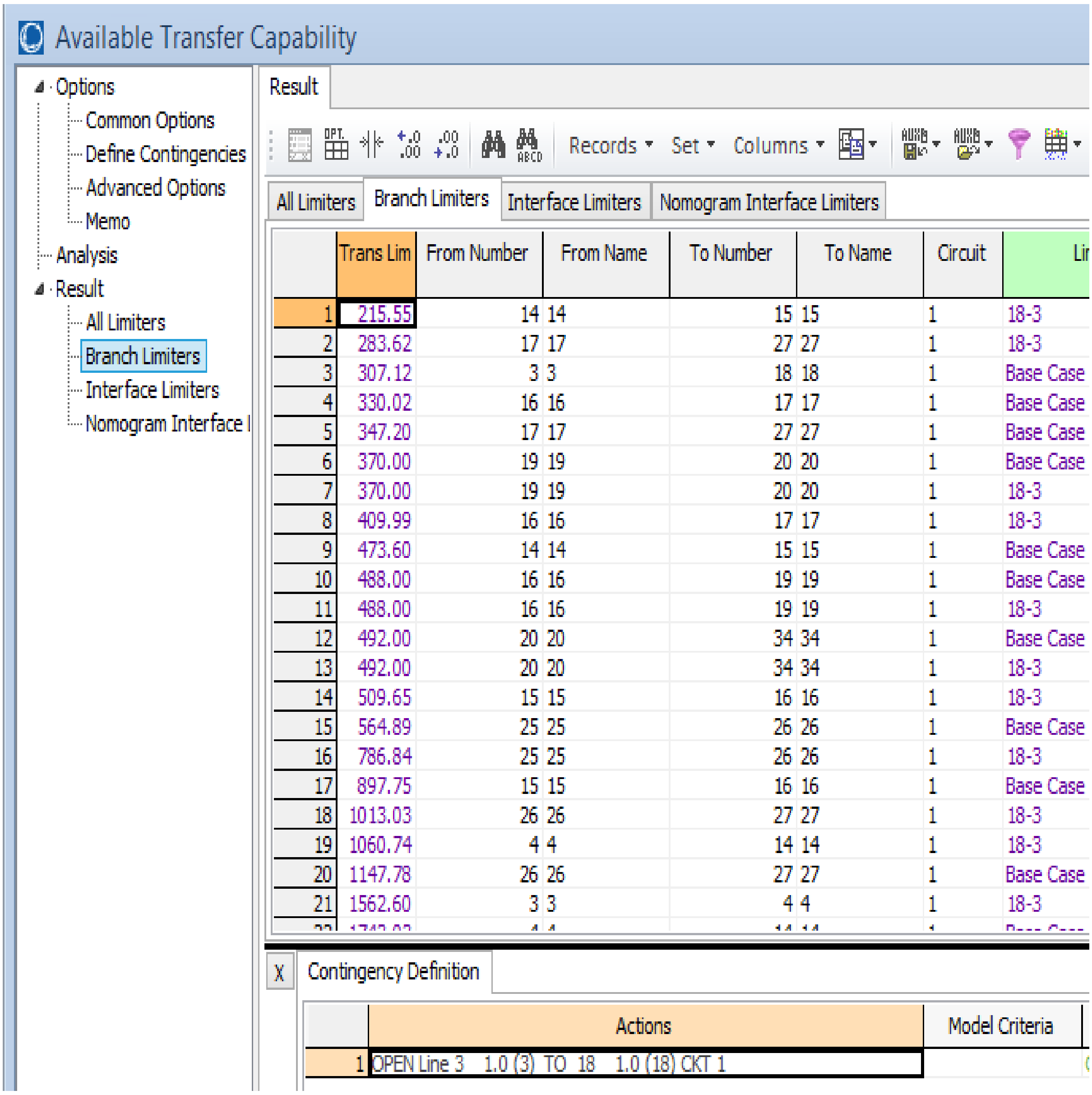


Figure 3.13: IEEE 39 Bus New England System in Powerworld Simulator ATC Value after Contingency

The Figure 3.13 shows the maximum power transfer capability of each line in IEEE 39 bus New England system where bus 34 is seller bus & bus 26 is a buyer bus and a line outage is performed for line connected between bus 14 & 15 has the least value of maximum transfer capability. Thus, the ATC value in this case is 215.55 MW. If ATC value is increased from this, it will violate the limits of line connected between bus 14 & 15.

Table 3.6: Comparison of Powerworld Simulator and Matlab ATC Results between 34-26 Bus

DCPTDF Method	**ATC Value Using Powerworld Simulator (MW)**	**ATC Value Using MATLAB (MW)**	**Limiting Factor**
Base Case	307.12	307.1222	Line 3-18
Line Out 18-3	215.55	215.5485	Line 14-15

The Table 3.6 gives a comparison of ATC values for IEEE 39 bus New England system calculated in Powerworld Simulator software and MATLAB software. The method used to find ATC value in DCPTDF method. These are cases considered in this table.

The first case gives the ATC value for base case of IEEE 39 bus New England system. The tabale shows that the ATC value calculated in Powerwolrd Simulator is 307.12 MW and that in case of MATLAB software is 307.1222 MW. It indicated the ATC value in both the software are almost similar. The limiting factor in this case is line connected between bus 3 and 18. It shows that the line connected between bus 3 & 18 has the least maximum power transfer capability in this case.

The second case gives the ATC value for line outage performed between buses 18 and 3. It can be seen that the ATC value calculated in both software are almost same. The ATC value calculated in Powerworld Simulator is 215.55 MW & in MATLAB is 215.05485 MW. The limiting factor for this case is line connected between bus 14 and bus 15. It ATC value increases from 215.55 MW, the limits of this line gets violated.

ATC value for base case is 307.12 MW and for the case of line outage between bus 18 & 3 is 215.55 MW. It shows that for the case of line outage, the ATC value decrease. Also, the limiting factor for the case of line outage changes compared to base case.

3.10.3 ATC Results between (34-26) Bus after Line Outage (Contingency) between (25-26) Bus and Renewable Added on Bus 16 (50 MW)

Table 3.7: Comparison of Powerworld Simulator and Matlab ATC Results between 34-26 Bus

DCPTDF Method	ATC Value Using MATLAB (MW)	Limiting Factor
Base Case	307.1222	Line 3-18
Line Out 25-26	170.5000	Line 17-27
Reduction in Renewable Power (10MW)	297.4554	Line 26-27

The Table 3.7 gives the ATC value for IEEE 39 bus New England sysytem calculated in MATLAB software. The DCPTDF method is used to find the ATC value in this case. There are 3 cases considered in this table.

In the first case, the base case of IEEE 39 bus New England system is considered. The ATC value for this case is 307.1222 MW and the limiting factor is the line connected between bus 3 and 18. It shows that if ATC value is increased from 307.1222 MW, it will violate the limits of line connected between bus 3 to 18.

In second case, the ATC value is calculated considering a line outage between bus 25 and 26. The ATC value calculated in this case is 170.50 MW. The limiting factor is line connected between bus 17 and 27. It shows that if ATC value increase from 170.50 MW the line limits of line connected between bus 17 and 27 gets violated.

In the third case, a renewable power source is added on bus 16 having maximum power capacity of 50 MW. A line outage between buses 25 & 26 is considered along with a reduction of 10 MW in generation of renewable source. At this time the ATC value is 297.4554 MW. The limiting factor is line connected between bus 26 to 27. It indicates that if ATC value is increased from 297.4554 MW, it will violated the limits of line connected between bus 26 to 27.

From this table, it can be seen that the ATC value in base case system is 307.1222 MW and in case where renewable is added in the system with reduction in its generation is 297.4554 MW. So, when renewable is added in the system and its generation is reduced, it reduces the ATC value compared to base case ATC value.

Chapter 4

Conclusion and Future Scope

4.1 Conclusion

For large power network, it is important to manage power transfer by respective load dispatch centres in short duration with fair approximation and accuracy. With the consideration of same, computation time period and storage of data, PTDF has been found suitable method for calculation of ATC. Developed MATLAB script for base case and different contingency cases is verified correctly by simulation of such system in Powerworld Simulator. Effect of formulated base case, different contingency case and reduction in renewable power case on ATC has been studied by MATLAB code.

4.2 Future Scope

Multiple renewable energy generation along with commercial generators will be considered for calculation of ATC.
Effect of uncertain nature of renewable energy on ATC will be included.
Different intermittency such as variation in solar irradiation and change in wind speed will be consider for ATC calculation.

References

[1] M. Patel and A. A. Girgis, "Review of Available Transmission Capability (ATC) Calculation Methods," *Electrical and computer engineering department,IEEE*, 2009.

[2] M. Y. Patel and A. A. Girgis, "New Iterative Method for Available Transfer Capability Calculation," *in Proc. IEEE Power and Energy Soc. General Meeting*, 2011.

[3] A. Khairuddin and N. A. Bakar, "ATC Determination Incorporating Wind Generation," *IEEE 7th International Power Engineering and Optimization Conference*, no. June, pp. 501–506, 2014.

[4] "CALCULATION OF AVAILABLE TRANSFER CAPABILITY (ATC)." [Online]. Available: http://nptel.ac.in/courses/108101005/transmissioncongestionmanagement/calculationofatc.html

[5] S. Deka, "Available Transfer Capability Calculations Considering Outages," *International Conference on Power and Embedded Drive Control*, pp. 161–166, 2017.

[6] M. Hojabri and H. Hizam, *Available Transfer Capability Calculation, Applicationsof MATLAB in Science and Engineering.* Intech., 2011.

[7] B. Stott and O. Alsac, "Optimal load flow with steady-state security," in *Power Systems Laboratory*, 1973, pp. 745–751.

[8] S. Busan, M. M. Othman, I. Musirin, A. Mohamed, and A. Hussain, "A New Algorithm for the Available Transfer Capability Determination," *Mathematical Problems in Engineering*, pp. 1–30, 2010.

[9] J. J. Graninger and W. D. Stevenson, *"Power System Analysis"*. Mc Graw Hill, 1989.

[10] A. J. Wood and B. F. Wollenberg, *Power Generation, Operation, and Control*, 2nd ed. New York: Wiley, 1984.

[11] A. A. F. P.M. Anderson, *Power System Control and Stability.* Ames,IA: Iowa State University Press, 1997.

Appendix A

Branch Data and Generator Data for Test Systems

Table A.1: Branch Data of IEEE 6 Bus System

Line no.	**From bus -to bus**	**Resistance (p.u.)**	**Reactance (p.u.)**	**Total Line Charging Susceptance (p.u.)**	**Maximum Apparent Power Flow (MVA)**
1	1-2	0.1	0.2	0.04	40
2	1-4	0.05	0.2	0.04	60
3	1-5	0.08	0.3	0.06	40
4	2-3	0.05	0.25	0.06	40
5	2-4	0.05	0.1	0.02	80
6	2-5	0.1	0.3	0.04	30
7	2-6	0.07	0.2	0.05	90
8	3-5	0.12	0.26	0.05	70
9	3-6	0.02	0.1	0.02	90
10	4-5	0.2	0.4	0.08	20
11	5-6	0.1	0.3	0.06	40

Table A.2: Generation and Demand Data of IEEE 6 Bus System

Bus no.	**Generation Power (MW)**	**Demand Power (MW)**
1	0	0
2	50	0
3	60	0
4	0	70
5	0	70
6	0	70

Table A.3: Branch Data of IEEE 9 Bus System

Sr no.	From bus	To bus	Resistance (p.u.)	Reactance (p.u.)	Maximum Apparent Power Flow (MVA)
1	4	1	0	0.0576	250
2	2	7	0	0.0625	200
3	9	3	0	0.0586	200
4	5	4	0.010	0.068	200
5	6	4	0.017	0.092	200
6	7	5	0.032	0.161	200
7	9	6	0.039	0.170	200
8	7	8	0.0085	0.05760	100
9	8	9	0.0119	0.1008	200

Table A.4: Generation and Demand Data of IEEE 9 Bus System

Bus no.	Generation Power (MW)	Demand Power (MW)
1	0	0
2	163	0
3	85	0
4	0	0
5	0	125
6	0	90
7	0	0
8	0	100
9	0	0

Table A.5: Branch Data of IEEE 30 Bus System

Sr no.	**From bus**	**To bus**	**Resistance (p.u.)**	**Reactance (p.u.)**	**Maximum Apparent Power Flow (MVA)**
1	1	2	0.0192	0.0575	130
2	1	3	0.0452	0.1852	130
3	2	4	0.057	0.1737	65
4	2	5	0.0472	0.1983	130
5	2	6	0.0581	0.1763	65
6	3	4	0.0132	0.0379	130
7	4	6	0.0119	0.0414	90
8	4	12	0	0.256	65
9	5	7	0.046	0.116	70
10	6	7	0.0267	0.082	130
11	6	8	0.012	0.042	32
12	6	9	0	0.208	65
13	6	10	0	0.556	32
14	6	28	0.0169	0.0599	32
15	8	28	0.0636	0.2	32
16	9	10	0	0.11	65
17	9	11	0	0.208	65
18	10	17	0.0324	0.0845	32
19	10	20	0.0936	0.209	32
20	10	21	0.0348	0.0749	32
21	10	22	0.0727	0.1499	32
22	12	13	0	0.14	65
23	12	14	0.1231	0.2559	32
24	12	15	0.0662	0.1304	32
25	12	16	0.0945	0.1987	32
26	14	15	0.221	0.1997	16
27	15	18	0.107	0.2185	16
28	15	23	0.1	0.202	16
29	16	17	0.0824	0.1932	16
30	18	19	0.0639	0.1292	16
31	19	20	0.034	0.068	32
32	21	22	0.0116	0.0236	32
33	22	24	0.115	0.179	16
34	23	24	0.132	0.27	16
35	24	25	0.1885	0.3292	16
36	25	26	0.2544	0.38	16
37	25	27	0.1093	0.2087	16
38	28	27	0	0.396	65
39	27	29	0.2198	0.4153	16
40	27	30	0.3202	0.6027	16
41	29	30	0.2399	0.4533	16

Table A.6: Generation and Demand Data of IEEE 30 Bus System

Bus no.	Generation Power (MW)	Demand Power (MW)
1	200	0
2	80	21.7
3	0	3.4
4	0	7.6
5	50	94.2
6	0	0
7	0	22.8
8	35	30
9	0	0
10	0	5.8
11	30	0
12	0	11.2
13	40	0
14	0	6.2
15	0	8.2
16	0	3.5
17	0	9
18	0	3.2
19	0	9.5
20	0	2.2
21	0	17.5
22	0	0
23	0	3.2
24	0	8.7
25	0	0
26	0	3.5
27	0	0
28	0	0
29	0	2.4
30	0	10.6

Table A.7: Branch Data of IEEE 39 Bus New England System

Sr no.	**From bus**	**To bus**	**Resistance (p.u.)**	**Reactance (p.u.)**	**Maximum Apparent Power Flow (MVA)**
1	2	31	0.0035	0.0411	250
2	39	31	0.001	0.025	250
3	3	2	0.0013	0.0151	750
4	25	2	0.007	0.0086	500
5	4	3	0.0013	0.0213	250
6	18	3	0.0011	0.0133	100
7	5	4	0.0008	0.0128	500
8	14	4	0.0008	0.0129	500
9	6	5	0.0002	0.0026	1000
10	8	5	0.0008	0.0112	500
11	7	6	0.0006	0.0092	750
12	11	6	0.0007	0.0082	750
13	8	7	0.0004	0.0046	500
14	9	8	0.0023	0.0363	250
15	39	9	0.001	0.025	250
16	11	10	0.0004	0.0043	750
17	13	10	0.0004	0.0043	500
18	14	13	0.0009	0.0101	500
19	15	14	0.0018	0.0217	100
20	16	15	0.0009	0.0094	500
21	17	16	0.0007	0.0089	500
22	19	16	0.0016	0.0195	1000
23	21	16	0.0008	0.0135	500
24	24	16	0.0003	0.0059	250
25	18	17	0.0007	0.0082	500
26	27	17	0.0013	0.0173	250
27	22	21	0.0008	0.014	1000
28	23	22	0.0006	0.0096	250
29	24	23	0.0022	0.035	750
30	26	25	0.0032	0.0323	250
31	27	26	0.0014	0.0147	500
32	28	26	0.0043	0.0474	250
33	29	26	0.0057	0.0625	500
34	29	28	0.0014	0.0151	500
35	12	11	0.0016	0.0435	250
36	12	13	0.0016	0.0435	100
37	6	1	0	0.025	1000
38	10	32	0	0.02	1000
39	19	33	0.0007	0.0142	1000
40	20	34	0.0009	0.018	1000
41	22	35	0	0.0143	1000
42	23	36	0.0005	0.0272	1000
43	25	37	0.0006	0.0232	1000
44	2	30	0	0.0181	500
45	29	38	0.0008	0.0156	1000
46	19	20	0.0007	0.0138	250

Table A.8: Generation and Demand Data of IEEE 39 Bus System

Bus no.	**Generation power (MW)**	**Demand power (MW)**
1	0	9.2
2	0	0
3	0	322
4	0	500
5	0	0
6	0	0
7	0	233.8
8	0	522
9	0	0
10	0	0
11	0	0
12	0	7.5
13	0	0
14	0	0
15	0	320
16	0	329
17	0	0
18	0	158
19	0	0
20	0	628
21	0	274
22	0	0
23	0	247.5
24	0	308.6
25	0	224
26	0	139
27	0	281
28	0	206
29	0	283.5
30	250	0
31	0	0
32	650	0
33	632	0
34	508	0
35	650	0
36	560	0
37	540	0
38	830	0
39	1000	1104