Minimize the Transmission Loss in Power System Expansion with Integrating Distributed Generation and Compensator

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Abstract- In the power system to expanding Transmission network lines, Transmission expansion planning (TEP) is generally determined by peak demands. To improve the efficiency and sustainability of energy systems, attention has been paid to demand response programs (DRPs) and distributed generation (DG). DRPs and DG will also have significant impacts on the controllability and economics of power systems, from short-term scheduling to long-term scheduling planning. In this system, a non-linear economic design for responsive loads is introduced, based on the price flexibility of demand and the customers' benefit function. If any outages of generation system need power to balancing of power demand to implement wind and compensator. The planning Methodology is then demonstrated on an IEEE 14-bus system in order to show the feasibility of the proposed algorithm.

Keywords— *Transmission Expansion Planning, Demand Response Programs, Distributed Generation, Demand*

I. INTRODUCTION

Electrical energy systems are confronted with significant challenges regarding how to reach a clean, reliable and economical energy supply. Compensator is to compensating reactive power when Q_limit oscillating. Distributed electricity generators, such as small-scale wind turbines and solar plants, are currently expected to take an increasing share of power generation due to energy security and climate change concerns [2, 3]. On the other hand, distributed generation (DG) can be highly intermittent and uncertain. Hence, network planners are likely to face emerging security and reliability issues for a power network incorporating a high DG penetration [4, 5]. Though the characteristics of different DG combinations have been investigated widely in the literature, there still exist gaps and obstacles in power system planning and reliability evaluation [1].

Furthermore, there are many uncertainties involved in transmission expansion planning (TEP) in a deregulated power industry , such as the load predictions of distribution companies, the operating and bidding information of the generation firms, regulation and policy changes, and the DG outputs [6, 7]. Moreover, the deregulation of energy systems has introduced conflicting objectives among the different stakeholders. The central contribution of deregulation was to create a competitive market environment to maximize overall social welfare and to control the operating constraints of the power systems [8].

II. PROBLEM IDENTIFICATION

In IEEE-14 bus system in normal operating conditions all bus voltage in stable state that means voltage magnitude limits are in range between 1.1 V(p.u) < Vi (p.u) < 0.95 (p.u).If any outage (Forced or schedule outage) occurring generation will failure it output become zero. Remaining generators are overloaded generator limits between Gi_min<Gi<Gi_max. If exceeding Gi_max limit generator gets heated and transmission losses also increases to overcome this problem additionally DG's and compensator has provided in proposed system [7].

A. System Constraints

There are two types of constraints.

- Equality constraints.
- Inequality constraints.

1) Hard Type - The hard type constraints have constant and definite values for ex-the tapping range of an on load tap changing transformer. These constraints are very rigid in their values and don't entertain changes in them.
2) Soft Type - The soft type constraints are not very rigid to changes and offer some flexibility in changing their values, for ex - phase angles and nodal voltages.

The basic equality constraints are:

$$P_p = \{ e_p(e_q G_{pq} + f_q B_{pq}) + f_p(f_q G_{pq} - e_p B_{pq})\} \quad (2.1)$$

$$Q_p = \{ f_p(e_q G_{pq} + f_q B_{pq}) - e_p(f_q G_{pq} - e_p B_{pq})\} \quad (2.2)$$

Where $V_p = e_p + jf_p$ (real and imaginary components of voltage at the pth node)

And $Y_{pq} = G_{pq} - jB_{pq}$ (the nodal conductance and susceptance)

The following are the primary categories of inequality constraints:

- Generator constraints.
- Voltage constraints
- Running spare capacity constraints.
- Transformer tap settings.
- Transmission line constraints.

$Ppmin \leq Pp \leq Ppmax$ and $Qpmin \leq Qp \leq Qpmax$

Thermal consideration limits the maximum active power generation whereas flame instability of a boiler limits the minimum active power generation. Similarly the maximum and minimum reactive power generation is limited by overheating of the rotor and the stability limit of the machine respectively

$$|V_{pmin}| \leq |V_p| \leq |V_{pmax}| \text{ and } \delta_{pmin} \leq \delta_p \leq \delta_{pmax}$$

The variation in voltage magnitude should be within a prescribed limit for satisfactory operation of the equipment's connected to the system otherwise additional use of voltage regulators will make the system cost ineffective

These constraints are needed during the incident of forced outages of one or more alternators of the system and the unexpected load in the system. The total generation should be in such way that in addition to meet the load demand and losses a, minimum spare should be available.

The minimum tap setting in an auto transformer should be zero and the maximum should be one i.e. $0 \leq t \leq 1$.

Similarly if tappings are provided on the secondary side of a two winding transformer then, $0 \leq t \leq n$, where n is the ratio of transformation.

Thermal capability of the circuit limits the flow of active and reactive power through the transmission line and is expressed as $C_p \leq C_{pmax,}$ where C_{pmax} defines the maximum loading capacity of the pth line.

B. Power Flow Analysis by Newton-Raphson Method

- To maintain acceptable voltage profile it is necessary to maintain the voltage magnitude of generator buses distributed throughout the system at values higher than 1.0 per unit.
- At these buses only P-injection and voltage magnitude are specified and hence they are called P-V buses.
- While solving power flow problem the voltage magnitude at the P-V buses are required to be held at specified value provided the reactive power generation at this bus is within the reactive limits QG_{max} and QG_{min}.

Power Flow Model

- Number the PQ buses first then the PV buses and the slack bus is the last bus.
- Let
  - NV be the number of PV bus
  - NP be the number of P equations to find unknown δ (which is equal to $N-1$ equations)
  - NQ be the number of Q equations to find unknown V (which is equal to $N-1-NV$ equations)
- State vector (Dimension NP+NQ)

  $$x = (\delta_1, \delta_2, \dots . \delta_{NP}, V_1, V_2, \dots . . V_{NQ},)^t \quad (2.3)$$
- Number of equations is equal to number of unknowns (NP+NQ). Select the equations as follows
  - Slack bus δ and V known
  - PV bus δnot known only P equation
  - PQ bus and V unknown both P and Q equation

At the k[th] bus the real and reactive power injections are given by

$$FP_k = P_k(\delta, V) - PI_{k,sch} = 0, \text{ where } k = 1,2, \dots . . NP \quad (2.4)$$

$$FQ_k = Q_k(\delta, V) - QI_{k,sch} = 0, \text{ where } k = 1,2, \dots . . NQ \quad (2.5)$$

Where

$$P_k(\delta, V) = V_k \sum_{m=1}^{N} V_m \left[G_{km} \cos\delta_{km} + B_{km} \sin\delta_{km}\right], \quad \text{Where } k = 1,2, \dots . . NP \quad (2.6)$$

$$Q_k(\delta, V) = V_k \sum_{m=1}^{N} V_m \left[G_{km} \sin\delta_{km} - B_{km} \cos\delta_{km}\right], \quad \text{Where } k = 1,2, \dots . . NQ \quad (2.7)$$

The above equations can be compactly represented as

$$F(\delta, V) = 0 \quad (2.8)$$

$$F(x) = 0,$$

Where

$$x = (\delta_1, \delta_2, \dots . \delta_{NP}, V_1, V_2, \dots . . V_{NQ},)^t \quad (2.9)$$

Compact power flow equation has to be solved using N-R method to obtain the state vector through iterative process. Once the solution is obtained the unknown real and reactive injections and power flow in each line can be computed.

C. Static Synchronous Compensator

The Static Synchronous Compensator (STATCOM) is a shunt device of the Flexible AC Transmission Systems (FACTS) family using power electronics to control power flow and improve transient stability on power grids. The STATCOM regulates voltage at its terminal by controlling the amount of reactive power injected into or absorbed from the power system. When system voltage magnitude is low, the STATCOM generates reactive power (STATCOM capacitive). When system voltage magnitude is high, it absorbs reactive power (STATCOM inductive).

The variation of reactive power is performed by means of a Voltage-Sourced Converter (VSC) connected on the secondary side of a coupling transformer. The VSC uses forced-commutated power electronic devices (GTOs, IGBTs or IGCTs) to synthesize a voltage V2 from a DC voltage source [12]. The principle of operation of the STATCOM is explained on the figure 2.1 above showing the active and reactive power transfer between a source V1 and a source V2.

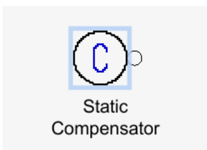

Figure No 2.1 Symbol of static synchronous compensator

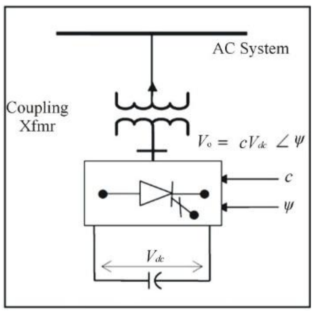

Figure No 2.2 Structure of static synchronous compensator

Usually a STATCOM is installed to support electricity networks that have a poor power factor and often poor voltage regulation. There are however, other uses, the most common use is for voltage stability. A STATCOM is a voltage source converter (VSC)-based device, with the voltage source behind a reactor. The voltage source is created from a DC capacitorand therefore a STATCOM has very little active power capability. However, its active power capability can be increased if a suitable energy storage device is connected across the DC capacitor. The reactive power at the terminals of the STATCOM depends on the amplitude of the voltage source and structure show above figure 2.2. For example, if the terminal voltage of the VSC is higher than the AC voltage at the point of connection, the STATCOM generates reactive current; conversely, when the amplitude of the voltage source is lower than the AC voltage, it absorbs reactive power. The response time of a STATCOM is shorter than that of a static VAR compensator (SVC), mainly due to the fast switching times provided by the IGBTs of the voltage source converter. The STATCOM also provides better reactive power support at low AC voltages than an SVC, since the reactive power from a STATCOM decreases linearly with the AC voltage (as the current can be maintained at the rated value even down to low AC voltage).

D. DFIG (Distribution Generation)

Doubly fed electrical generators are similar to AC electrical generators, but have additional features which allow them to run at speeds slightly above or below their natural synchronous speed. This is useful for large variable speed wind turbines, because wind speed can change suddenly. When a gust of wind hits a wind turbine, the blades try to speed up, but a synchronous generator is locked to the speed of the power grid and cannot speed up. So large forces are developed in the hub, gearbox, and generator as the power grid pushes back [10]. This causes wear and damage to the mechanism. If the turbine is allowed to speed up immediately when hit by a wind gust, the stresses are lower and the power from the wind gust is converted to useful electricity.

One approach to allowing wind turbine speed to vary is to accept whatever frequency the generator produces, convert it to DC, and then convert it to AC at the desired output frequency using an inverter. This is common for small house and farm wind turbines. But the inverters required for megawatt-scale wind turbines are large and expensive.

Doubly fed generators are one solution to this problem. Instead of the usual field winding fed with DC, and an armature winding where the generated electricity comes out, there are two three-phase windings, one stationary and one rotating, both separately connected to equipment outside the generator and structure show above figure 2.3. Thus the term "doubly fed".

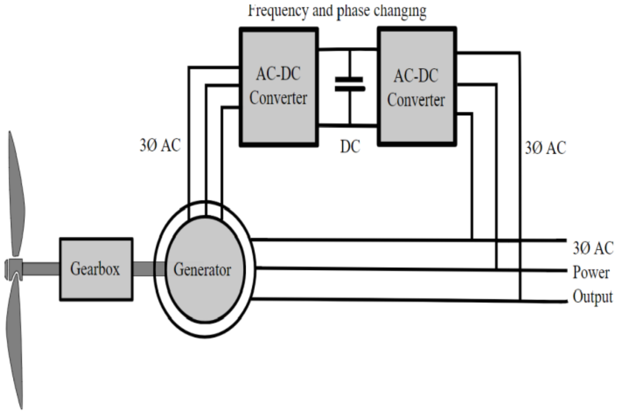

Figure No 2.3 Structure Double Fed Induction Generator

One winding is directly connected to the output, and produces 3-phase AC power at the desired grid frequency. The other winding (traditionally called the field, but here both windings can be outputs) is connected to 3-phase AC power at variable frequency [7]. This input power is adjusted in frequency and phase to compensate for changes in speed of the turbine.

Adjusting the frequency and phase requires an AC to DC to AC converter. This is usually constructed from very large IGBT semiconductors. The converter is bidirectional, and can pass power in either direction. Power can flow from this winding as well as from the output winding.

III. MODELLING OF LOAD

The choices regarding system reinforcements and system performance is mostly based on the results of power flow and stability simulation studies. For performing analysis of power system, models must be integrated to include all relevant system components, such as generating stations, sub stations, transmission and distribution peripherals and load devices [12]. Much attention has been given to modelling of generation and transmission or distribution devices. But the modelling of loads have received much less attention and remains to be an unexplored frontier and carries much scope for future development. Recent studies have revealed that representation and modelling of load can have a great impact on analysis results. Efforts in the directions of improving load-models have been given prime importance.

Advantages of load modelling in power flow studies

- The variation of power demand with voltage enables better control capacity.
- Actual calculation of active and reactive power demand at respective buses.
- Control of over and under voltage at load buses.
- Minimization of losses.
- Improvement in voltage profile.
- Reduction of Incremental Fuel Cost.

A. Classification Of Load Models:

Load models are broadly classified into two groups:

This model expresses the reactive and active power, at a particular instant of time, as a function of the magnitude of bus bar voltage and frequency. Both static and dynamic load components use static load models. The static load is model is given as an exponential function of voltage,

$$P_d = P_0 (V/V_0)^{\alpha} \quad (3.7)$$

$$Q_d = Q_0 (V/V_0)^{\beta} \quad (3.8)$$

Where,

P_d = Active power demand of load.
Q_d = Reactive power demand of load.
P_0 = Consumption of active power at rated voltage, V_0.
Q_0 = Consumption of reactive power at rated voltage, V_0.
α = Active power expoment.
β = Reactive power expoment.
V = Supply voltage.
V_0 = Rated voltage.

In Dynamic load model the active and reactive power at a particular instant of time is represented as a function of the magnitude of voltage and frequency. Dynamic load models are often used in studies regarding voltage stability, inter-area oscillations and long term stability.

B. Power System Analysis Tool (PSAT)

PSAT is a MATLAB toolbox for electric power system analysis and control. The command line version of PSAT is also GNU Octave compatible. PSAT includes power flow, continuation power flow, optimal power flow, small signal stability analysis and time domain simulation. All operations can be assessed by means of graphical user interfaces (GUIs) and a Simulink-based library provides an user friendly tool for network design. PSAT core is the power flow routine, which also takes care of state variable initialization. Once the power flow has been solved, further static and/or dynamic analysis can be performed. These routines are:

1. Continuation power flow,
2. Optimal power flow,
3. Small signal stability analysis,
4. Time domain simulations,
5. Phasor measurement unit (PMU) placement.

In order to perform accurate power system analysis, PSAT supports a variety of static and dynamic component models.

C. System Formation

Load flow analysis is the backbone of the power system studies and design, and through it the voltage magnitude and phase angle at each bus and the complex power flowing in each transmission line can be obtained. We are use the load-flow to perform a sensitivity analysis of the IEEE-14 bus system.IEEE-14 bus data shown in table 3.1. We find the maximum complex power flowing in each transmission line in case of no fault and in case of any one generation outages or fault in the steady state condition [11]. The results of this analysis helps identify the most minimizing total losses.

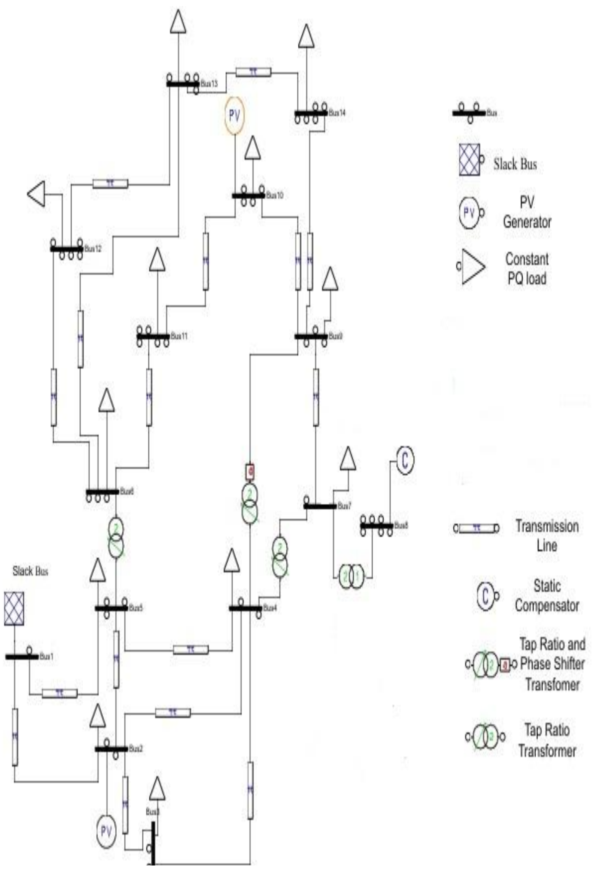

Figure No 3.1 IEEE-14 BUS system

Table No 3.1 Load Data for IEEE 14 Bus System

Bus No	P load [p.u.]	Q load [p.u.]
Bus1	0	0
Bus2	0.1044	2.0024
Bus3	4.3158	2.286
Bus4	4.6752	2.046
Bus5	4.1044	2.0024
Bus6	7.1688	2.106
Bus7	5.1688	2.106
Bus8	0	0
Bus9	0.465	0.2334
Bus10	0.123	0.0852
Bus11	4.045	1.2342
Bus12	5.0654	2.0278
Bus13	10.156	4.0856
Bus14	5.2146	1.08

Analysis of IEEE-14 Bus system generation equals to load and losses in system before outages voltage limits are not exceeding between two limits. In each bus real and reactive load given in p.u representation in table 3.1.

Table No 3.2 Line Flow Analysis Data for IEEE 14 Bus System

From Bus	To Bus	Line	P Flow [p.u.]	Q Flow [p.u.]
Bus1	Bus5	1	16.71872	2.48966
Bus1	Bus2	2	38.91163	-84.2631
Bus9	Bus7	3	-0.64963	155.9953
Bus14	Bus9	4	-5.58167	10.57583
Bus10	Bus9	5	-0.41177	99.07221
Bus10	Bus11	6	1.08877	-6.26841
Bus13	Bus12	7	-3.59139	-3.97769
Bus14	Bus13	8	0.36707	-11.6558
Bus2	Bus3	9	8.50109	19.59586
Bus2	Bus4	10	13.31199	55.03486
Bus4	Bus3	11	-3.80086	-38.1715
Bus5	Bus2	12	-16.6741	-59.0759
Bus5	Bus4	13	3.9509	43.58444
Bus11	Bus6	14	-2.96871	-7.52351
Bus13	Bus6	15	-6.28516	-11.9613
Bus12	Bus6	16	-8.68022	-6.0226
Bus5	Bus6	17	25.26442	28.93701
Bus4	Bus7	18	8.4339	94.25028
Bus8	Bus7	19	0	-185.781
Bus4	Bus9	20	7.08249	51.63122

System real power and reactive power flow and real and reactive power losses are shown above table 3.2Total power generation, load and losses are given in table 3.3.

Table No 3.3 Total Generation, Load and Losses Data for IEEE 14 Bus System

Total Generation (MW)(p.u)	82.07446
Total load (MW) (p.u)	71.9014
Total losses (MW) (p.u)	10.17306

Above analysis of total generation, load and losses are will be balancing equal if mismatch losses and generation losses are high in the system.

IV. ANALYSIS OF AFTER OUTAGES

If outage occurs in Bus no 10 generation is failure and remaining generators are overloaded voltage magnitude level reduced below 0.95 p.u, Q limit also exceeding its limits.

Table No 4.1 Voltage magnitude and Phase Angle Data for IEEE 14 Bus System

Bus	Voltage magnitude [p.u.]	phase [rad]
Bus10	**0.99536**	-0.0125
Bus14	**0.997**	-0.022
Bus7	**0.93604**	-0.00936
Bus9	**0.9862**	-0.00929

In above analysis table 4.1 voltage magnitude reduced below 0.9 p.u at Bus 10,7,9 and 14.This reduce of voltage magnitude effect of outage of generation on Bus 10 remaining generators to take loads on Bus 10.Remaining generator to exceeding its limits gets over heated losses increasing in system. Voltage level below 0.95 system voltage regulation will be effected.

Table No 4.2 Line Flow analysis Data for IEEE 14 Bus System

From Bus	To Bus	Line	P Flow [p.u.]	Q Loss [p.u.]
Bus9	Bus7	3	**0.15868**	5.8225
Bus4	Bus7	18	**7.21505**	8.02121

Above analysis table 4.2 of line flow P_flow and Q_flow higher than all other buses because of Bus 10 generation is outage the generation having 0.8 p.u (MW).The generation is isolated remaining generation gets over loaded 0.8 p.u(MW) getting from the 2 generations [5]. Total generation pull down to 78.89 p.u (MW) and load is 71.90 p.u (MW) but losses get more amount of energy of generation. Therefore losses are high generation gets reduced low level.

Table No 4.3 Total Generation, Load and Losses Data for IEEE 14 Bus System

Total Generation (MW)(p.u)	78.89409
Total load (MW) (p.u)	71.9014
Total losses (MW) (p.u)	8.26907

Above analysis table power not balancing 0.6 p.u power needed for losses to overcome this problem additionally static synchronous compensator and DFIG (Distribution generation).

A. Analysis Of After Integrating Dg And Compensator

In the Modified IEEE-14 Bus system to improve voltage stability and reduction of losses to be minimized arranging of wind generation and compensator as shown in figure 4.1. In the Bus 7 voltage magnitude is lower compared to other Buses the Static Synchronous Compensator is fixed.

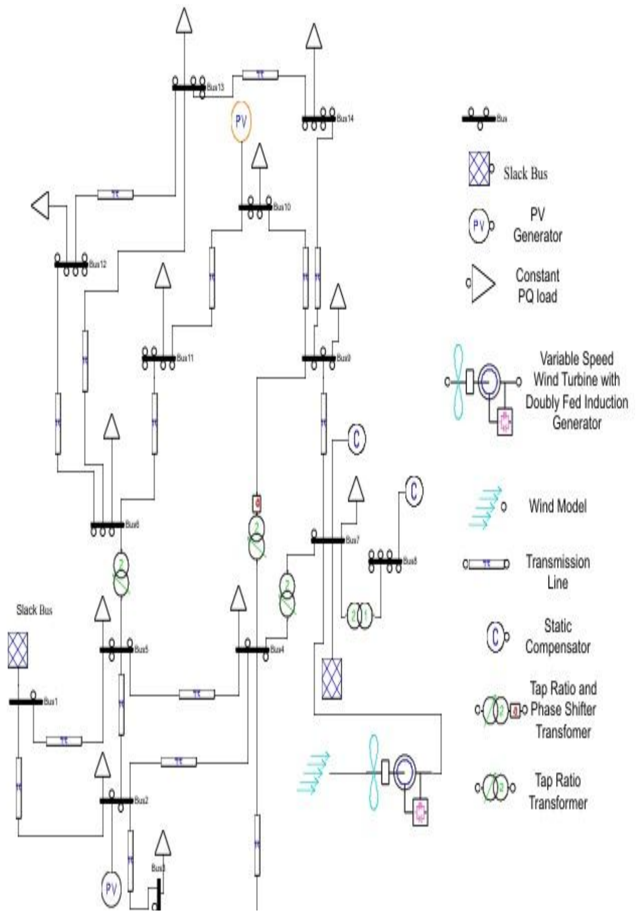

Figure No 4.1 Modified IEEE 14 Bus System

The Static Synchronous Compensator (STATCOM) is a shunt device of the Flexible AC Transmission Systems (FACTS) family using power electronics to control power flow and improve transient stability on power grids [6]. The STATCOM regulates voltage at its terminal by controlling the amount of reactive power injected into or absorbed from the power system. When system voltage is low, the STATCOM generates reactive power (STATCOM capacitive). When system voltage is high, it absorbs reactive power (STATCOM inductive).

Table No 4.4 STATCOM Data for Modified IEEE 14 Bus System

Rating name	Unit	Value
Power and Voltage	[MVA KV]	[100 25]
Voltage magnitude	[p.u]	[1.00]
Qmax and Qmin	[p.up.u]	[0.8 -0.2]

Bus 7 Real and Reactive power flow higher than other buses Static Synchronous Compensator lightly Real power compensating but not enough to compensating the total generation in 10^{th} Bus. To supply the power Distribution Generation will be fixed that means in this proposed system Renewable energy source act as Distribution Generation use this renewable energy source the voltage magnitude of all Buses will be stabilizing the wind generation is renewable

energy source in this proposed system. Doubly fed induction generation is used in this system. Because of more advantage using this system of other wind generations.

Doubly fed electrical generators are similar to AC electrical generators, but have additional features which allow them to run at speeds slightly above or below their natural synchronous speed. This is useful for large variable speed wind turbines, because wind speed can change suddenly. When a gust of wind hits a wind turbine, the blades try to speed up, but a synchronous generator is locked to the speed of the power grid and cannot speed up [7]. So large forces are developed in the hub, gearbox, and generator as the power grid pushes back. This causes wear and damage to the mechanism. If the turbine is allowed to speed up immediately when hit by a wind gust, the stresses are lower and the power from the wind gust is converted to useful electricity.

One approach to allowing wind turbine speed to vary is to accept whatever frequency the generator produces, convert it to DC, and then convert it to AC at the desired output frequency using an inverter [12]. This is common for small house and farm wind turbines. But the inverters required for megawatt-scale wind turbines are large and expensive.

Table No 4.5 DFIG Data for Modified IEEE 14 Bus System

Rating name	Unit	Value
Power, Voltage and frequency	[MVA KV HZ]	[200 25 60]
Stator resistance and reactance	[p.up.u]	[0.01 0.10]
Rotor resistance and reactance	[p.up.u]	[0.01 0.08I]
Inertia constants	[KWs/KVA]	[3]
Pitch control gain and time constant Kp, Tp	[p.u. s]	[10 3]
Voltage control gain	Kv [p.u.]	[10]

Totally 20 wind generations are connected in compose block

B. Power flow results

Table No 4.6 Analysis for Modified IEEE 14 Bus System

Bus	Voltage Magnitude [p.u.]	Phase [rad]
Bus10	1.0383	-0.00734
Bus14	1.03771	-0.01569
Bus7	1	0
Bus9	1.03253	-0.00417

To adding compensator and distributed generation after analysis of system all bus voltage magnitude are within limits shown above table 4.6.

C. Line flows

Table No 4.7 Line Flow Analysis Data for Modified IEEE 14 Bus System

From Bus	To Bus	Line	P Flow [p.u.]	Q Flow [p.u.]
Bus9	Bus7	3	-9.96093	77.74851
Bus4	Bus7	18	-4.40595	52.07339

Table No 4.8 Power generation, Load and Losses Data for Modified IEEE 14 Bus System

Total Generation (MW)(p.u)	86.58303
Total load (MW) (p.u)	71.9014
Total losses (MW) (p.u)	14.68163

To integrating of DFIG and Static compensator at Bus 7 all bus voltage stabilizing, Reducing losses from 217.09(MW) p.u to 129.83(MW) p.u at bus 7 and system total losses reducing upto 20% of total generation. The DFIG providing 25.3 (MW) p.u power of total energy it will compensating of generation outage and Static Synchronous Compensator to compensating of required amount of reactive power.

In above analysis of table 4.8 and 4.7 losses are reduced to minimum level and total losses are reduced minimum level.

In previous existing systems total system losses are reduced to 20% to 23% and in proposed system total system losses of total generation reduced to 17% to 20%.

CONCLUSION

The increasing penetration of DG into the main power systems has caused uncertainties and produced new difficulties for Transmission System. DRPs, as one of the important supports in smart grids, have been considered, together with their impacts on the handling and control of power systems, varying from short term to long-term scheduling. The results illustrate that DRPs can be a relevant resource which can significantly reduce the total losses in the system.

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