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HYDRO AND WIND PARTICIPATION FOR CONGESTION MANAGEMENT IN HYBRID ELECTRICITY MARKET

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Abstract

Purpose- The congestion management has become challenging issue in the deregulated power system as it threatens the system security and reliability. Due to the integration of renewable energy sources and frequent variations in wind power, load and the requirement of reserves with sufficient ramp rate, there is a challenge in the management of the congestion in the system. The pumped storage units with less starting time and lesser cost can take care of these unexpected variations and reduce their impact on power system operation. The aim of this paper is to provide a model for managing congestion in a hybrid power system. The purpose of this paper is to present the congestion management technique based on generator rescheduling for a pool and bilateral power supply market considering secure bilateral transactions between them. The impact of renewable sources has been considered for congestion management. The operational constraints with and without renewable source units are included in the optimization problem.

Design/methodology/approach- The availability of water during the congestion will determine whether hydro units participate in congestion management. The problem has been modelled to include the water discharge and water availability during congestion management. The availability of wind during the congestion will determine whether wind units participate in congestion management. The wind model uses the Weibull PDF, and a sample of the hourly wind speed was obtained by using a Monte Carlo simulation (MCS). The selection of the lines is based on the sensitivity factors based on congestion distribution factors, and the multi-line congestion cases with two or three lines have been taken into consideration. The created model was applied in the CONOPT solver in the GAMS optimization tool. The model has been called in to MATLAB platform by using GAMS-MATLAB interfacing to retrieve the solution. The results have been obtained for IEEE-24 bus Reliability Test System with hydro and wind generators with adding some modification into it.

Findings- To reduce the cost of congestion, the model provide an effective operation schedule for pumped storage units and conventional units. The effects of different wind power with the use of pumped storage unit and wind power has been incorporated in the congestion

management solution. The best combination of renewable source are 2Hydro+1Wind Units as saving of congestion cost are 1403.6$/hr and 1855.18$/hr in Case1 (3-line congestion) and Case2 (2-line congestion) respectively. Thus, with significant renewable energy sources, they have considerable impact on managing congestion. In future electricity markets, these sources will have significant share and will play a key role for avoiding congestion and helping the ISO/TSO for better management of the network.

Research limitations/implications – In practical power system network, since there are integration of the significant renewable energy sources, in such hybrid systems, the issue of congestion management must be addressed. In competitive electricity market structure, the renewable energy sources can also participate for congestion mitigation and it is essential to develop methodology to address the issues of their role in management of congestion. However, the intermittent sources needs their dispatch in real time and market mechanisms need to be developed by the ISO to take advantage of renewable energy sources participation in controlling congestion. This paper has attempted this issue based on the bids offered by the renewable energy sources and participates in the congestion management.

Practical implications –Hybrid systems are essential in modern time not only to meet rising energy demand and to reduce emission but also the sources can participate in the congestion management during the time of peak load requirements offering themselves for controlling congestion. While deciding the dispatch of the generating units, many factors have to be considered for economic, secure and reliable operation of the power system. This model addresses two issues in a hybrid system namely congestion cost minimization along with the bids offered by the renewable energy sources including the conventional units fulfilling other operational constraints. When both conventional generators and renewable energy sources are contributing to the congestion in the pool and hybrid electricity markets, the model offers an effective dispatch plan.

Application: The application has been shown by analyzing the two cases. In the first case only thermal generators are participating for the congestion management based on their bids declared to the ISO taking the presence of the renewable energy sources in the system but they are not participating in the congestion management. They have power available to the system during the congestion.

In the second case, we have taken the participation of the renewable energy sources where these sources are declaring their bids to the ISO for their role in the congestion management. Along with the conventional generators.

In future power system, this study will have impact on the system operation where renewable energy sources are offering themselves for the congestion control. Whatever congestion cost the ISO will collect from the market, the amount can be paid to the renewable energy sources and this is how the sources will become sustainable as well as the revenue will be generated from the electricity market.

Originality/value – Renewable energy penetration in the present power system is an integral part. In the competitive power market, the renewable energy sources can participate in the

congestion management process. In this paper, we have considered the participation of the wind and hydro generators in the congestion management process. This paper finds that the congestion cost with the participation of the renewable energy sources and it is observed that the cost reduced significantly in a hybrid system. The suggested model offers a timetable for the operation of conventional and pumped storage units with variable wind power output and load conditions throughout operating horizon. The coordinated optimization has been implemented on IEEE 24 bus test system.

Keywords Congestion management, Renewable energy source (Wind and Hydro units), Generation rescheduling, missed-integer-non-linear programming (MINLP).

Paper type- Research paper

1 Introduction

In competitive electricity market, it has becomes mandatory to develop and promote Renewable Energy Source (RES). The increase in RES integration can cause frequent congestion of the network. Congestion management process is to prioritize the mechanism to commit transactions so that overloading of the network is avoided. Congestion management plays an important role in deregulated power system to maintain security and reliability. In pool based electricity market, bids are submitted to Independent System Operator (ISO) from GENCOS and DISCOS and take a decision for day- a-head generation and undergo with generation and consumption at acceptance scheduled clearing price (Lo K.L, Yuen Y.S, Snider L.A, 2000). To manage the congestion in transmission lines schedule can be altered for both the producers and consumers. In bilateral electricity market, it has to be ensured the security level of bilateral transactions during congestion management. The ISO play a vital role for congestion management and ensure the effective coordination with re-dispatch in hybrid market (Sood Y.R, Padhy N.P, Gupta H.O, 2002; Galiana F.D, and Ilic M, 1998). During congestion management the RES's are not preferred due to their unpredictable nature but RES's are the best alternate solution to fulfill the energy requirement as these are environmental friendly. If we differentiate among all renewable energy sources, the hydro and wind power generation is cheaper and cleaner. Hydro power generation is the second largest power generation available in India and wind power generation is also in developing stage. The hydro and wind units have less operational cost and have a speedy turn on characteristics. Due to these features, this helps to meet peak and emergency requirement of power. It is necessary to explore the role of congestion management when hydro and wind units are present along with thermal units (J. W. Cheng J.W, Galiana F.D, McGillis D.T, 1998). The scheduling in thermal units is decided only for market clearing price and scheduling in hydro and wind units are considered for price sucker which has been upgraded their revenue by bidding and energy price is close to the system marginal price (Peng T, Tomsovic K, 2003).

In literature, many approaches have been utilized to study congestion management based on as DC and AC congestion distribution factors, rescheduling of generators and demand, Zonal approach, reactive power support and stochastic approach have also be used (Kumar A et al.,2004; M. Esmaili et al.,2010; Singh A.K, Parid S.K,2013). Xio.Y et al. (2009) proposed benders decomposition technique for congestion management by considering hybrid market. In (Dutta, Singh, 2008; Balaraman S el al., 2011; Hajforoosh S et al., 2012), Particle swarm optimization approach has been stand on optimal rescheduling generator. The active power generator is rescheduled in congestion management based on Fuzzy adaptive bacterial foraging approach was proposed in (Venkaish et al., 2011). In (Granelli G et al, 2006; Surender Reddy S et al., 2009), an approach for congestion management using Genetic Algorithm was proposed. In (Sood Y.R et al., 2007; Acharya N et al., 2007; Murali M et al, 2014), the congestion management based on nodal pricing was proposed. The different type of approach FFA method, PSO, RSM, SA proposed for congestion management in (Balaraman S, Kamaraj N, 2011; X. S. Yang, 2010). In (Kumar A, Sekhar C,2012; Kumar A, Mittapalli R.K, 2014; Kumar A, Sekhar C,2013), congestion management with application of FACTS device based on PSO was proposed in deregulated environment. In (Verma Y.P, Kumar Ashwani, 2014), a hybrid electricity market consists of hydro and thermal units and congestion management placed on rescheduling. Authors in (Verma Y.P, Kumar Ashwani, 2014) have only considered hydro-thermal combination. Since, wind is having significant contribution in power system, its impact on the congestion management is essential to consider with hydro and thermal combination.

With the renewable energy sources in significant amount in the present power system, it is essential to analyze the system with the impact of renewable energy sources whenever the congestion prevails in the system. The renewable energy sources can participate during congestion by declaring their bids in the market to resolve the issues of congestion. In this paper, authors addressed the problem of solving the congestion management in thermal dominated system along with the participation of the renewable energy sources and finding their impact on the congestion management.

In the paper, the congestion cost is minimized without (Thermal unit only) and with (Hydro units, Wind units, 1Hydro + 2Wind units and 2Hydro+ 1Wind units) renewable energy sources are concurred for congestion management. The mix-integer non-linear programming has been adopted in congestion management for (bilateral and pool) electricity market. In congestion management the congestion cost reduced by rescheduling of generators. Through GD matrix secure bilateral transactions have been consolidated between producers and consumers. The bids of both without (thermal generating units) and with renewable source (with Wind units, Hydro units, 1Hydro+2Wind units and 2 Hydro+1Wind units) generating units submit to ISO. In optimization problem added the operational constraints of with and without renewable source units. During the congestion, the cases of Wind units and Hydro units are dependences on the scope of wind and the level of water in congestion management respectively. The Weibull PDF is utilized for wind model and the Monte Carlo simulation (MCS) approach has been obtained hourly wind speed sample. The discharging of water, scope of water is modeled in the optimization problem during congestion management. The two congestion cases have been considered, Case1 (3-line congestion) and Case2 (2-line congestion) based on the sensitivity of line congestion. The optimization problem of congestion management has been solved by mixed-integer non-linear programming (MINLP) by using GAMS and MTLAB interfacing (Brooke A at el., 1998). The proposed approach applies to IEEE-24 bus Reliability Test System and results have been obtained.

2 Optimization model of Secure Bilateral Transaction

The most practical solution will be used in the hybrid electricity market in the future, when a pool will coexist simultaneously along with bilateral or multilateral transactions. In this type of market the participants are taken both types of agreement is being done during pool and

bilateral bids. Therefore, the hybrid market model gets more transmission access. The most suitable example for this category is California market model. There are several electricity market structures available in world and it implemented in different countries for different market structures with arrangements of two popular market (Bilateral and Pool Model) (Barroso L.A et al., 2005; Fang R.S, David A.K, 1999). The dispatching and scheduling is different for both market models on many issues, the system stability may be affected by constraints of transmission line and handling imbalances. Bilateral market model based concept, the proposed transactions deviations have to be minimized. The objective function is:
Minimize deviations

$$\left\{\sum_k \sum_j b_{kj}\left(GD_{kj} - GD_{kj}^0\right)^2\right\} \quad (1)$$

Subject to:
Equation (2) and (3) represent balances real and reactive power.

$$P_k = P_{gk} + P_{hk} + P_{wk} - P_{dk} = \sum_j^N V_k V_j Y_{kj} \cos\left(\delta_k - \delta_j - \theta_{kj}\right) \ \forall\, k = 1.2 \ldots \ldots \ldots . N \quad (2)$$

$$Q_k = Q_{gk} + Q_{hk} + Q_{wk} - Q_{dk} = \sum_j^N V_k V_j Y_{kj} \sin\left(\delta_k - \delta_j - \theta_{kj}\right) \ \forall\, k = 1.2 \ldots \ldots \ldots . N \quad (3)$$

Equations (4)-(7) represent the demand and generation power balance equations employing bilateral transaction matrix GD for hybrid market model

$$P_{db} = \sum_k GD_{kj} \quad (4)$$

$$P_{gb} = \sum_j GD_{kj} \quad (5)$$

$$P_g = P_{gb} + P_{gp} \quad (6)$$

$$P_d = P_{db} + P_{dp} \quad (7)$$

Equation (8) and (9) are power flow equation for bilateral and pool power

$$P_{fb} = DF\left(P_{gb} - P_{db}\right) \quad (8)$$

$$P_{fbp} = DF\left(P_{gp} - P_{dp}\right) \quad (9)$$

The net power flow in (10)

$$P_f = P_{fb} + P_{fp} \quad ($$

10)

Distribution factors (DF) can be obtained as discussed in (Kumar A, Srivastava S.C and Singh S.N, 2004). Every generator generates power between its generation capacities. Equations (11)-(13) are real and (14)-(16) are reactive power limit of thermal, hydro and Wind generators.

$$P_{gk}^{min} \le P_{gk} \le P_{gk}^{max} \quad ; \forall k \in G \tag{11}$$

$$P_{hk}^{min} \le P_{hk} \le P_{hk}^{max} \quad ; \forall k \in H \tag{12}$$

$$P_{wk}^{min} \le P_{wk} \le P_{wk}^{max} \quad ; \forall k \in W \tag{13}$$

$$Q_{gk}^{min} \le Q_{gk} \le Q_{gk}^{max} \quad ; \forall k \in G \tag{14}$$

$$Q_{hk}^{min} \le Q_{hk} \le Q_{hk}^{max} \quad ; \forall k \in H \tag{15}$$

$$Q_{wk}^{min} \le Q_{wk} \le Q_{wk}^{max} \quad ; \forall k \in W \tag{16}$$

Equation (17) and (18) are lines angle and voltage limits.

$$\delta_k^{min} \le \delta_k \le \delta_k^{max} \tag{17}$$

$$V_k^{min} \le V_k \le V_k^{max} \tag{18}$$

The transaction limits between the seller bus-k and buyer bus-j in (19)

$$GD_{kj}^{min} \le GD_{kj} \le GD_{kj}^{max} \le \min\left(P_{gk}^{max}, P_{dj}\right) \tag{19}$$

The MVA limit for the lines in (20)

$$\left|MVA_{kj}\right| \le MVA_{kj}^{max} \tag{20}$$

Between 1.05p.u to 0.95p.u are allowed variation of line voltage. The secure bilateral transaction matrix has been obtained from the equation given above and used to reduce the congestion cost in the optimization problem.

3 Mathematical model for Rescheduling of Generators during Congestion Management

The problem formulation of congestion management main objective are to minimize the congestion cost in an existing system consist of Wind and Hydro units. The operational equality and inequality constraints of Hydro, Wind and Thermal units with secure bilateral transactions. The up-and-down cost of power for the hydro, wind, and thermal producing units includes the cost of congestion management. The problem can represent mathematically in below:

Minimize

$$\mathrm{Ccost} = \sum_{k\in g}\left(C_k^{up}\Delta P_{gk}^{up}\right) + \left(C_k^{down}\Delta P_{gk}^{down}\right) + \sum_{k\in h}\left(C_k^{up}\Delta P_{hk}^{up}\right) + \left(C_k^{down}\Delta P_{hk}^{down}\right) + \sum_{k\in w}\left(C_k^{up}\Delta P_{wk}^{up}\right) + \left(C_k^{down}\Delta P_{wk}^{down}\right) \qquad (21)$$

3.1 The equality Constraints are:

The equation (22) is injected real and (23) are injected reactive power at each bus.

$$P_k = \sum_j^N V_k V_j Y_{kj}\cos\left(\delta_k - \delta_j - \theta_{kj}\right)\ \forall\ k = 1.2\ \ldots\ldots\ldots N \qquad (22)$$

$$Q_k = \sum_j^N V_k V_j Y_{kj}\sin\left(\delta_k - \delta_j - \theta_{kj}\right)\ \forall\ k = 1.2\ \ldots\ldots\ldots N \qquad (23)$$

During congestion management the total up and down generation should be equal (24)

$$\sum_k^N\left(\Delta P_{gk}^{up}\right) - \sum_k^N\left(\Delta P_{gk}^{down}\right) + \sum_k^N\left(\Delta P_{hk}^{up}\right) - \sum_k^N\left(\Delta P_{hk}^{down}\right) + \sum_k^N\left(\Delta P_{wk}^{up}\right) - \sum_k^N\left(\Delta P_{wk}^{down}\right) = 0\ ;\ \forall\ k \in N \qquad (24)$$

During congestion management the generator k rescheduled generation is equal to the up and down in generation and day-ahead schedule in (25).

$$P_{gnk} = P_k^0 + \Delta P_{gk}^{up} - \Delta P_{gk}^{down} + \Delta P_{hk}^{up} - \Delta P_{hk}^{down} + \Delta P_{wk}^{up} - \Delta P_{wk}^{down};\ \forall\ i \in N \qquad (25)$$

Equation (26) and (27) the injected real and reactive power respectively.

$$P_k = P_{gnk} - P_{dk} \qquad (26)$$

$$Q_k = Q_{gk} + Q_{hk} + Q_{wk} - Q_{di} \qquad (27)$$

The binary variables u_{hk} and v_{hk}^l are help for design the hydro units performance modeled by using piece–wise linear non- concave curves has been shown in Figure 2 and explain in (Afkousi-Paqaleh M, Fard A. A. T, Rashidinejad M, 2010). The status of hydro generating unit denotes by variable u_{hk} and during congestion management u_{hk} =1 than the unit is committed. When v_{hk}^l is 1, the limit of l_{th} block exceed due to discharge the water of the k_{th} unit. The hydro unit performance is neglected while a short term congestion management solution the head variations effect.

$$P_{hk}^0 + \Delta P_{hk}^{up} - \Delta P_{hk}^{down} = P_{hk}^{min} u_{hk} + \sum_{l=1}^L q_{hk}^l\ r_{hk}^l; \qquad \forall\ k \in H \qquad (28)$$

$$\emptyset_{hk} = \emptyset_{hk}^{min} + \sum_{l=1}^L q_{hk}^l\ ;\ \ \forall\ k \in H \qquad (29)$$

Hydro units ΔP_{hk}^{up} and ΔP_{hk}^{down} generation is dependent upon P_{hk}^{min} and its generating power produced by q_{hk}^l (water discharging for L period of total block) represent in equation (28). Equation (29) can be represented all block of periods l on water discharge.

3.2 The Inequality Constraints are:

Thermal, Hydro and Wind generating units are subjected to many inequality constraints. In equations (30), (31) and (32) the Hydro, Wind and as well as Thermal units generated rescheduled real power must remain within the limits.

$P_{gk}^{min} \leq P_{gk}^{0} + \Delta P_{gk}^{up} - \Delta P_{gk}^{down} \leq P_{gk}^{max} \; ; \forall k \in G$ (30)

$P_{hk}^{min} \leq P_{hk}^{0} + \Delta P_{hk}^{up} - \Delta P_{hk}^{down} \leq P_{hk}^{max} \; ; \forall k \in H$ (31)

$P_{wk}^{min} \leq P_{wk}^{0} + \Delta P_{wk}^{up} - \Delta P_{wk}^{down} \leq P_{wk}^{max} \; ; \forall k \in W$ (32)

In equations (33), (34) and (35) the reactive power limits of Wind, Hydro and Thermal units must also be acknowledged and specified.

$Q_{gk}^{min} \leq Q_{gk}^{0} \leq Q_{gk}^{max} \; ; \forall k \in G$ (33)

$Q_{hk}^{min} \leq Q_{hk}^{0} \leq Q_{hk}^{max} \; ; \forall k \in H$ (34)

$Q_{wk}^{min} \leq Q_{wk}^{0} \leq Q_{wk}^{max} \; ; \forall k \in W$ (35)

The equations (36) and (37) represent voltage and angle limits on the lines.

$V_{k}^{min} \leq V_{k} \leq V_{k}^{max}$ (36)

$\delta_{k}^{min} \leq \delta_{k} \leq \delta_{k}^{max}$ (37)

Limits of water discharging for the Hydro units are under its limit as given by (38)-(42)

$\emptyset_{hk}^{min} u_{hk} \leq \emptyset_{hk} \leq \emptyset_{hk}^{max}$ (38)

$q_{hk}^{l} \leq q_{hk}^{max,l} u_{hk} \; ; \forall \; l = 1, k \in H$ (39)

$q_{hk}^{l} \geq q_{hk}^{max,l} v_{hk}^{l} ; \forall \; l = 1, k \in H$ (40)

$q_{hk}^{l} \leq q_{hk}^{max,l} v_{hk}^{l-1} ; \forall \; l \neq 1, k \in H$ (41)

$q_{hk}^{l} \geq q_{hk}^{max,l} v_{hk}^{l} \; ; \forall \; l \neq 1, k \in H$ (42)

The amount of water allocated to the power producers during congestion management limits the hydro units' capacity. However, the water level for the scheduled power generator units must be met at least a day in advance of power generation.

$M\emptyset_{hk} \leq W_{hk} ; \forall k \in H$ (43)

Here, for converting m^3/s into H m^3/h a conversion factor M is used. The W_{hk} (water content) is appropriated at k_{th} bus for rescheduling in congestion management by Hydro generator company.

In equation (44) the MVA limit of congested transmission lines must be limited throughout power flow.

$P_{kj}^{2} + Q_{kj}^{2} \leq \left(S_{kj}^{max}\right)^{2}$ (44)

In enhancement to the upper constraints, for all the generating units the ramp rate limits are also used for up and down. According to equation (48)-(50) specified the ramp rates of wind, hydro and thermal units respectively.

$0 \leq \Delta P_{gk}^{up} \leq \Delta P_{gk}^{up,ramp} ; \forall k \in G$ (45)

$0 \leq \Delta P_{gk}^{down} \leq \Delta P_{gk}^{down,ramp} \; \forall k \in G$ (46)

$0 \leq \Delta P_{hk}^{up} \leq \Delta P_{hk}^{up,ramp} ; \forall k \in H$ (47)

$0 \leq \Delta P_{hk}^{down} \leq \Delta P_{hk}^{down,ramp} \; \forall k \in H$ (48)

$0 \leq \Delta P_{wk}^{up} \leq \Delta P_{wk}^{up,ramp} ; \forall k \in W$ (49)

$0 \leq \Delta P_{wk}^{down} \leq \Delta P_{wk}^{down,ramp} \; \forall k \in W$ (50)

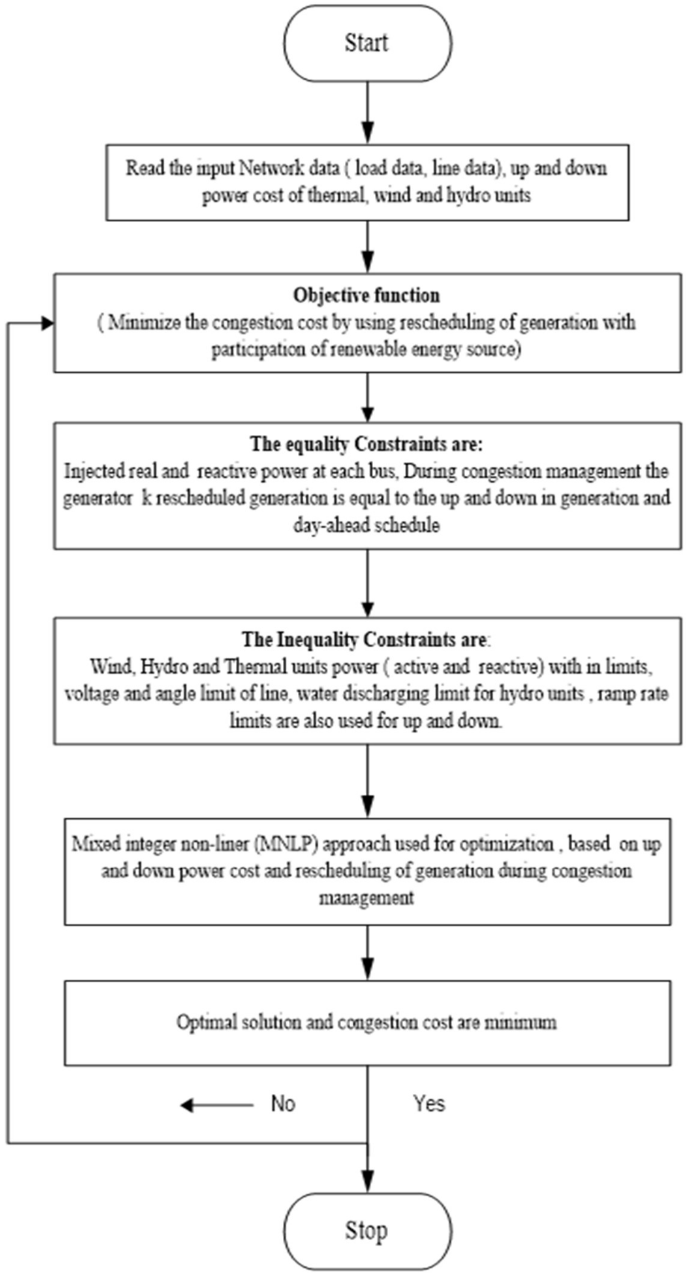

Fig.1 Flow chat of purposed methodology

In equation (51) - (52) represent the hybrid market model, generation and demand equation of power balance by using bilateral transaction GD matrix.

$P_{db} = \sum_k GD_{kj}$ (51)

$P_{gb} = \sum_j GD_{kj}$ (52)

$P_g = P_{gb} + P_{gp}$ (53)

$P_d = P_{db} + P_{dp}$ (54)

$GD_{kj}^{min} \leq GD_{kj} \leq GD_{kj}^{max}$ (55)

Where, P_g and P_{gn} are the day-ahead scheduled power and rescheduled power after congestion management respectively. In Fig 1 has been shown the purposed methodology for achieved the objective (minimization of congestion cost).

Table1 Hydro generator data for IEEE-24 bus system

P_h^{max} (MW)	P_h^{min} (MW)	Q_h^{max} (MVAR)	Q_h^{min} (MVAR)	Wf (Hm^3/h)	$\emptyset^{min}$ (m^3/s)	$\emptyset^{max}$ (m^3/s)
500	40	35	-5.0	1.4	10	100
590	81	54	-1.0	2.5	20	200
400	68	68	-50	1.5	10	120

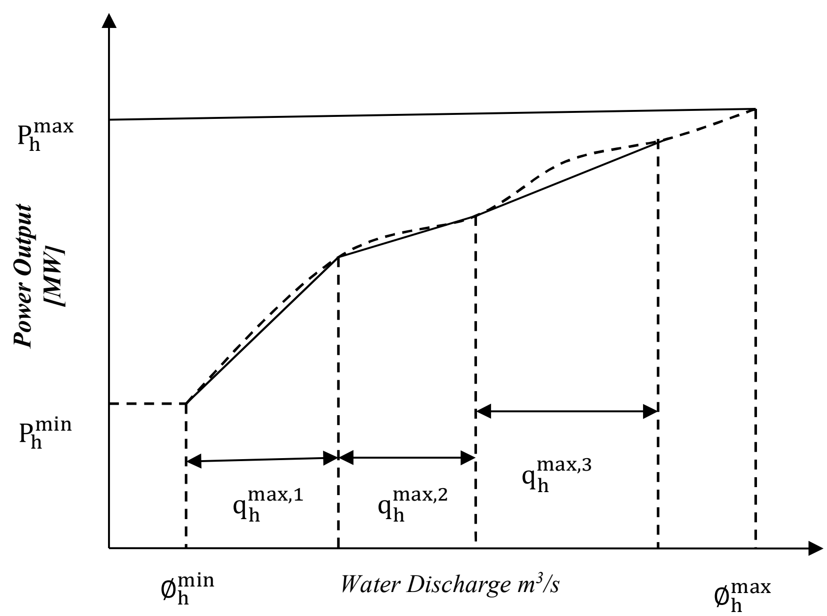

Fig. 2 Hydro units non-conclave piece-wise characteristics curves

4 Modeling of Wind Turbine Generation Pattern and Cost Function

The wind speed at the site is the most important factor in the generation of power by wind turbines and time-series models.(Kusiak A, Li W,2010), data mining algorithm (Abdel-Aal RE et al., 2009), and clustering approach(Kusiak A, Li W,2010) many other methods also to model wind behavior. In this wind model, we used Weibull PDF for the variation of wind speed (v) and wind speed related to its characteristic function. The output of a Wind Turbine as follows:

$$PDF_w(v) = \left(\frac{i}{c}\right)\left(\frac{v}{c}\right)^{(i-1)} \exp\left[-\left(\frac{v}{c}\right)^i\right]$$

(56)

$$i = \left(\frac{\sigma}{\mu}\right)^{-1.086}$$

(57)

$$c = \frac{\overline{\mu}}{\Gamma\left(\frac{1}{i}+1\right)}$$

(58)

Where i: is shape and c: is scale factor of the Weibull PDF,   : is means m/s and : is standard deviation m/s of weed speed, and hourly mean wind speed data for month of May over the first twelve year (1994-2005) (Abdel-Aal RE et al., 2009).Monte Carlo simulation (MCS) are used for obtaining hourly sample of wind speed.

The Wind turbine generated power is determined by its speed-power curve as follows:

$$P_k^w = \begin{cases} 0 & , if v \leq v_{in}^c or v \geq v_{out}^c \\ \frac{v - v_{in}^c}{v_{rated}^c - v_{in}^c} P_{k,r}^w & , if v_{in}^c \leq v \leq v_{rated}^c \\ P_{k,r}^w & , else \end{cases} \quad (59)$$

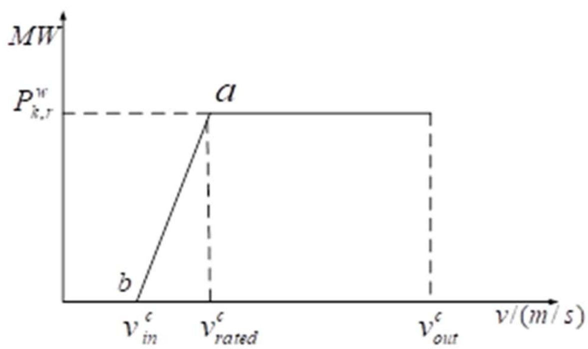

Fig.3 Wind turbine characteristics

Table.2 Technical characteristic of Wind turbine

Features	Turbine1	Turbine2
Rated power(MW) $P_{k,r}^w$	3	2
Cut-in speed(m/s) v_{in}^c	3	3
Rated speed(m/s) v_{rated}^c	15	15
Cut out speed(m/s) v_{out}^c	25	25

The is rated power and   are generated power of Wind turbine install in bus- k, and is the cut-out speed, is the cut-in speed and   are the rated speed of the Wind turbine. Each Wind turbine

(turbine 1, turbine 2) has been obtained the speed-power curve. The technical data is given in Table 2 (Atwa YM et al, 2010).Characteristics of wind turbine can be drawn as depicted by Fig.3.

In this, the average values of active power generation for each wind turbine (turbine1 and turbine2) are evaluated, as illustrated in Figures 4 and 5, respectively. It consist the wind plant for desired power level and consist 100 wind turbines in each wind plant. The average value of power generation, wind plant1 active power is 325.5 MW and wind plant2 active power is 217.7MW. The bid cost function of the wind turbine considered is:

$$P(C_{WT}) = a_{WT} + b_{WT} P_{WT} + c_{WT} P_{WT}^2 \qquad (60)$$

Where P (CWT) is the cost function of WT-based DG and PWT is the generated power in MW. The aWT , bWT , cWT are cost coefficient of Wind turbine in $, $/MWh, $/MWh2 . For Wind turbine1 cost function parameters are (aWT = 4.46$, bWT =17.83 $/MWh, cWT= 0.0027 $/MWh2) and Wind turbine2 cost function (aWT = 4.45$, bWT =17.54 $/MWh, cWT= 0.0028 $/MWh2). The data is available in (Crisostomi E, Liu M, Raugi M and Shorten R, 2014).

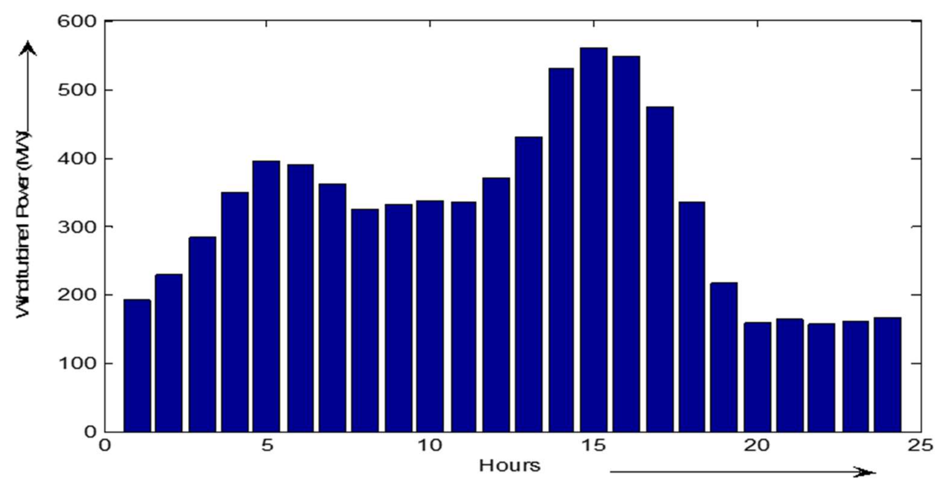

Fig.4 Wind turbine1 electricity generation pattern for 24 hours

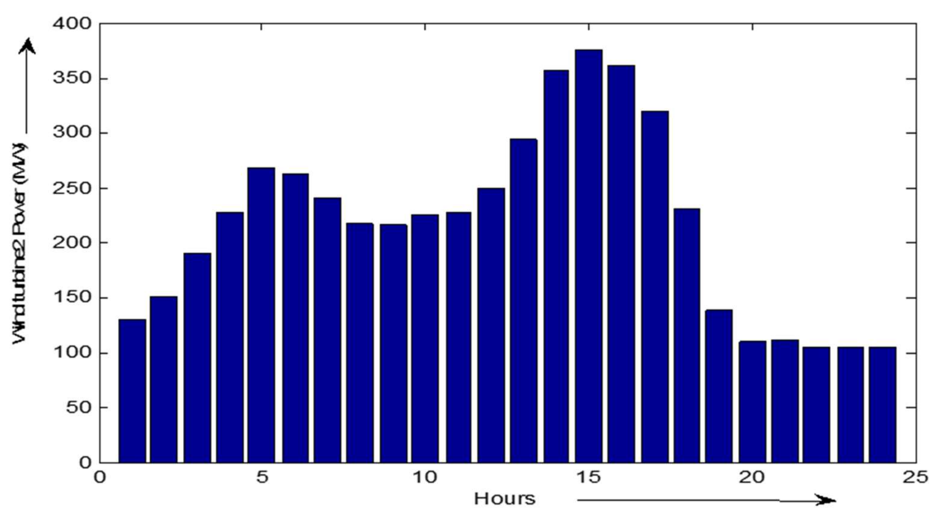

Fig.5 Wind turbine2 electricity generation pattern for 24 hours

5 Results and discussions

The simulation studies carried out on IEEE-24 bus system and have been solved the congestion management problem. The Wind turbine and Hydro based plants have been modified IEEE 24 bus test system. The rescheduling of generation with and without renewable source considering different combination of renewable source for minimization of congestion cost is presented. The cases taken are without renewable source (only existing thermal plants), with wind plants, with Hydro plants, with 2 Hydro+1 wind and with 2 wind and 1Hydro plants.

The eleven generators are connected at buses (1, 2,7,8,13,16,18,21,22, and 23) in the IEEE-24 system. The units of renewable source have been connected in bus number 8, 13, 18 and the remaining buses (1, 2, 7, 16, 21, 22, and 23) are having thermal generation. Two multi line congestion cases have been considered:

Case1 (3- line congestion) , with and without renewable source

Case2 (2- line congestion) congestion with and without renewable source.

The congested lines have been assumed having the rating of lines below the base case power flows. In a modified IEEE 24 bust test system hydro, wind units have been taken along with thermal units. A new bilateral transaction GD matrix as discussed in section 2 is obtained with the renewable sources. The GD transaction matrix obtained is shown in Fig.6. The obtained secure bilateral transaction matrix has been utilized during the congestion management problem.

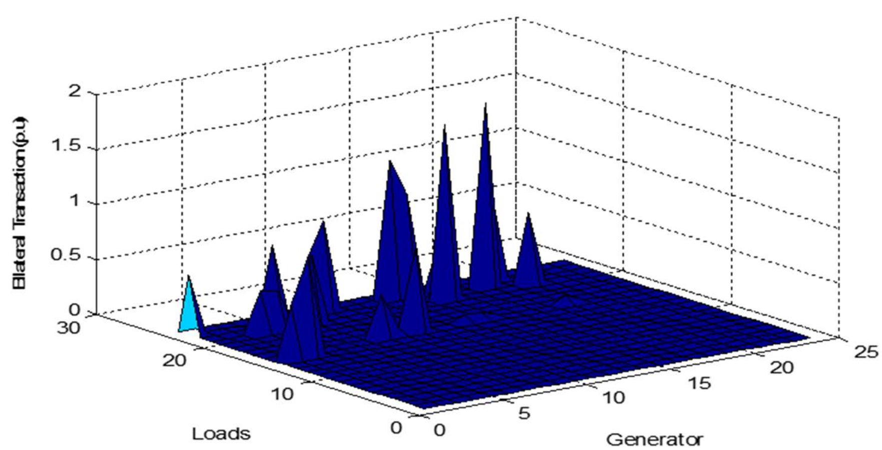

Fig.6 During congestion management secure bilateral transaction pattern

5.1 Case 1: 3-line congestion

In this case, the three lines (14-16, 6-10 and 15-16) have been considered as congested lines. Line (14-16) base power flow was 332.84 MVA, line (6-10) was 124.15 MVA and 226.33 MVA at line (15-16). Considering these three lines, the line flow limits are decreased from 500 MVA to 300 MVA, 175 MVA to 100MVA and 500 MVA to 150 MVA. The day-a-head P_g and new generation schedule P_gn , during congestion management the up - down change in power for without and with renewable source has been shown in Table 3. The new generation schedule of without and with renewable source has been shown in Fig 7.

Table3 Generation schedule with and without renewable energy source units participation in per unit

Gen	3L Congestion Line (15-16) ,(14-16) and (6-10) without renewable resource				3L Congestion Line (15-16) ,(14-16) and (6-10) with Wind Units			3L Congestion Line (15-16) ,(14-16) and (6-10) with Hydro Units			3L Congestion Line (15-16) ,(14-16) and (6-10) with 1Hydro+2 Wind Units			3L Congestion Line (15-16) ,(14-16) and (6-10) with 2Hydro+1 Wind Units		
	P_g	P_{gn}	ΔP_g^u	ΔP_g^d	P_{gn}	ΔP_g^u	ΔP_g^d	P_{gn}	ΔP_g^u	ΔP_g^d	P_{gn}	ΔP_g^u	ΔP_g^d	P_{gn}	ΔP_g^u	ΔP_g^d
1	1.52	1.52	-	-	1.52	-	-	1.52	.2356		1.52			1.52		
2	1.52	1.90	0.38	-	1.52	0.2645	-	1.75			1.78	0.2626		1.77	0.253	
7	1.5	2.09	0.59	-	1.5	-	-	1.5			1.5			1.5		
8*	2.4	2.4	-	-	2.513	0.2394	-	2.4			2.37		0.0218	2.4		
13*	2.36	2.36	-		3.65	0.50	-	3.086	.7228		3.75	0.50		3.43	0.189	
15	4.5	3.7	-	0.80	3.7	-	0.80	3.70		.80	3.7		0.80	3.7		0.80
16	1.5	1.55	0.05	-	1.55	0.05	-	1.55	.05		1.55	0.05		1.55	0.05	
18*	3.5	3.5	-	-	2.85	-	0.50	3.5			2.75		0.50	2.7		0.80
21	3.0	2.2	-	0.80	2.74	-	0.2675	2.448		.552	2.73		0.26	2.8		0.19
22	3.1	2.86	-	0.23	3.0	-	0.10	2.753		.3468	3.0		0.10	3.0		0.10
23	3.5	4.3	0.80	-	3.85	0.1855	-	4.19	.6904		3.70	0.2092		3.99	0.4961	

It can be observed that the up and down generation change of generators decides by the location of congested line. Line (6-10) was congested up to the units (2 and 7) didn't participate in congestion management, however when there is congestion on line (6-10) rescheduling by the units (2 and 7) is cost-effective. The renewable source units are not be engaged in congestion management thus the cost of congestion is high and the congestion management cost without renewable source unit is 5119.02$/hr. With renewable source in the congestion management, 4542.42$/hr, 4252.89$/hr, 4155.80$/hr and 3715.42$/hr are cost of congestion management with wind turbine unit, hydro unit, 1hydro+2wind unit and 2hydro+1wind unit respectively. The cost is shown in Fig.8. It is observed that with renewable sources the congestion cost reduces and the maximum reduction of congestion cost is with 2 hydro+ 1wind units in the system. Thus, renewable source units do have an impact on the overall cost and can be used in the congestion management problem economically.

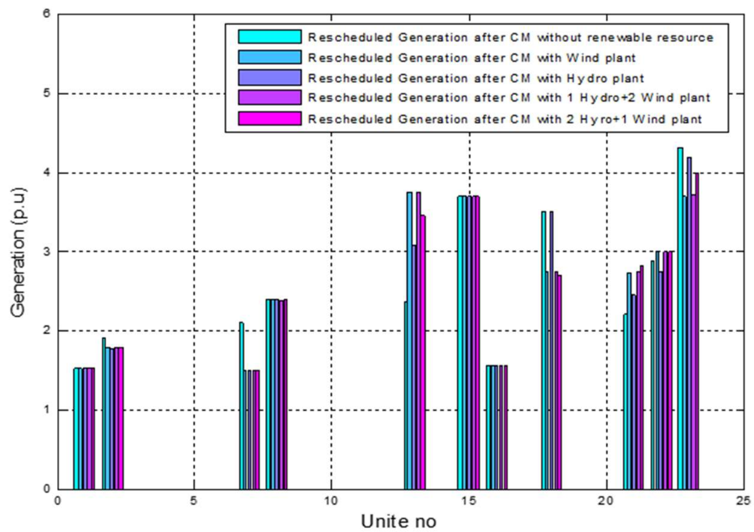

Fig.7 Generators rescheduling for Case1 (3- Line congestion) Congestion Management without and with renewable source

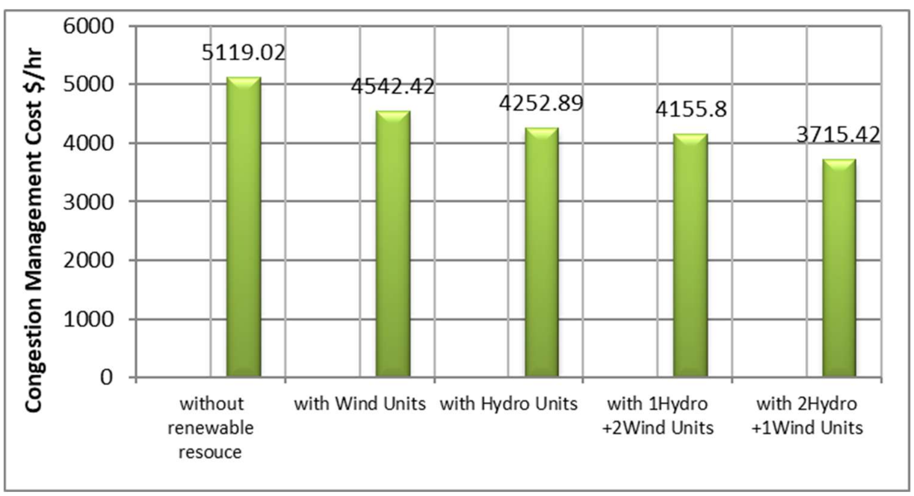

Fig.8 Case1 (3-line congestion) Congestion Management cost of with and without renewable resource

In Fig.9, Fig. 10, Fig 11, Fig. 12 and Fig. 13 has been shown, the (pool and bilateral) power demand and generation along with up and down power by without and with renewable sources (with wind units, with hydro units, with 1hydro+2wind units and with 2 hydro+1 wind units) units in congestion management for Case1(3-line congestion).

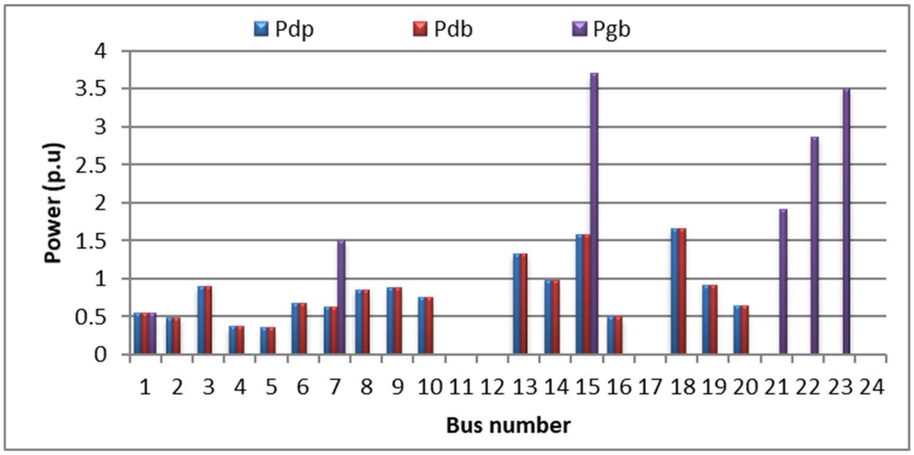

Fig.9 Bilateral and pool power generation in Case1 (3- line congestion) without renewable source

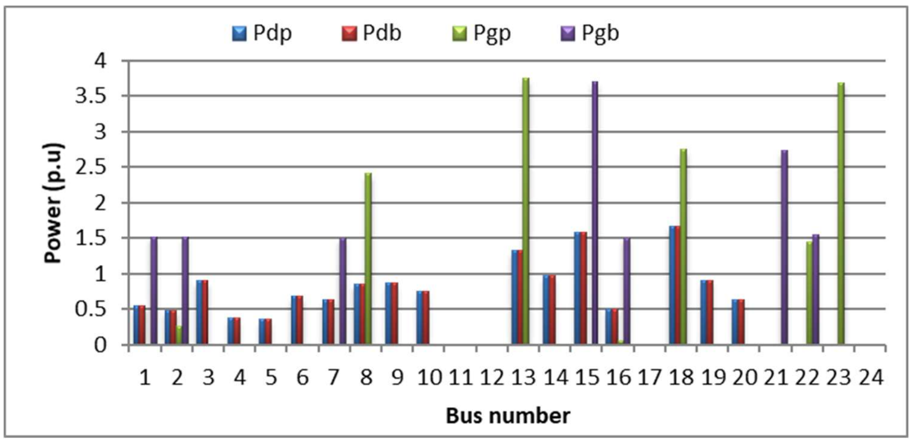

Fig.10 Bilateral and pool power generation in Case1 (3-line congestion) with Wind Unit

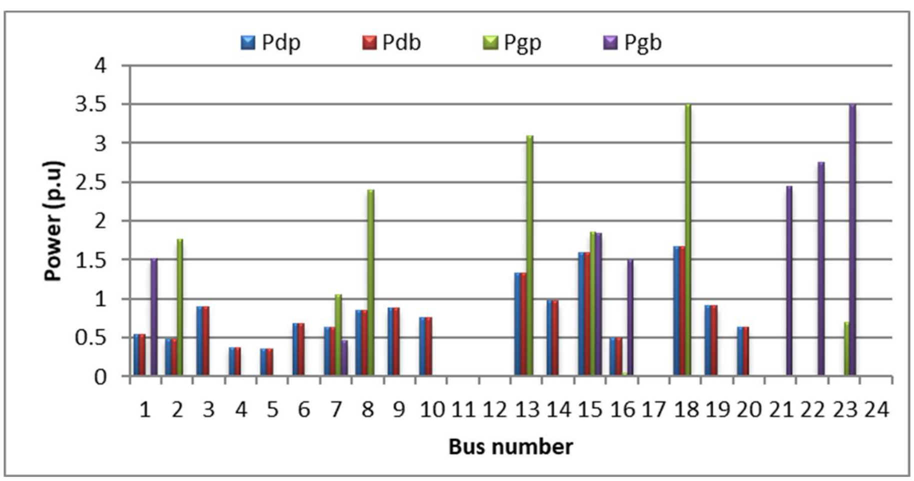

Fig.11 Bilateral and pool power in Case1 (3- line congestion) with Hydro Units

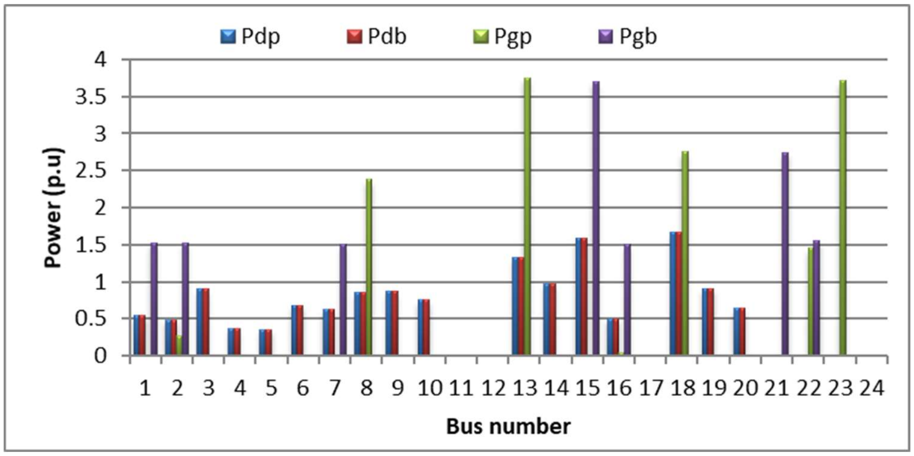

Fig.12 Bilateral and pool power in Case1 (3-line congestion) congestion with 1Hydro+2Wind Units

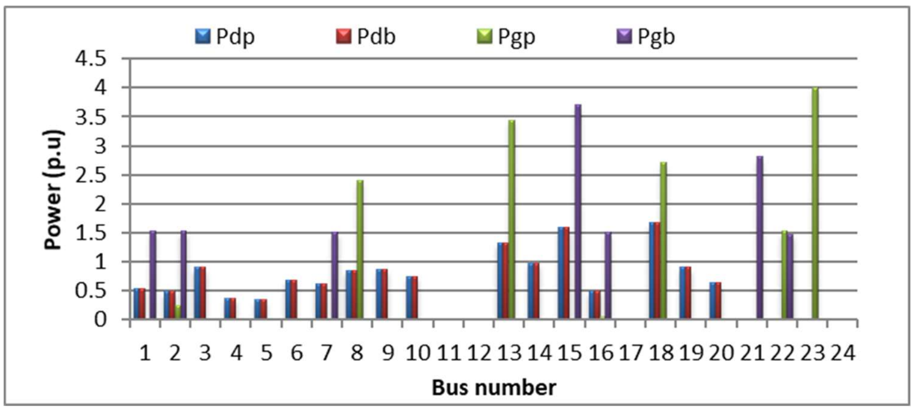

Fig.13 Bilateral and pool power in Case1 (3-line congestion) with 2Hydro+1Wind Units

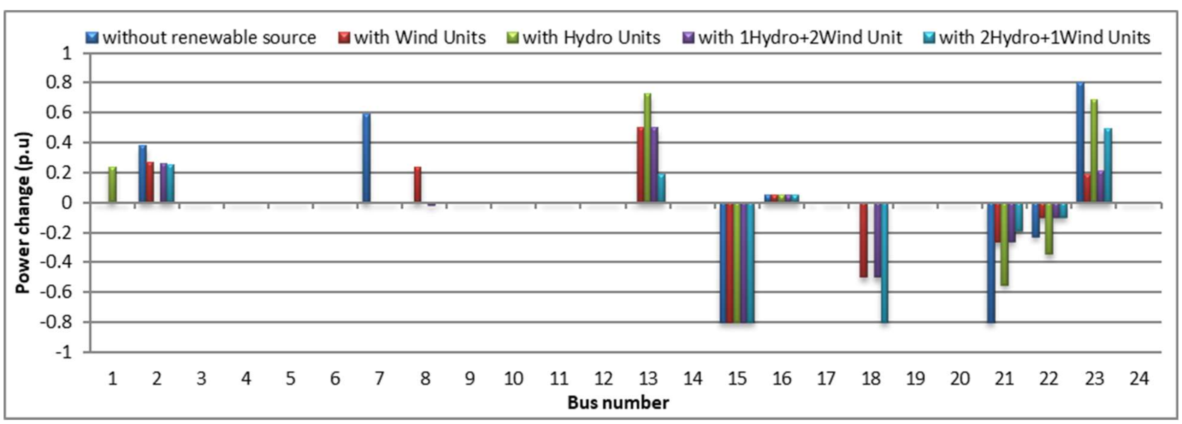

Fig.14 Generation Units up and down without and with renewable source at Case1 (3-line congestion) of congestion management

The up and down generation without and with renewable source at case1 (3-line congestion) in congestion management have been shown in Fig.14. The up and down generation reduces with renewable sources, therefore, accordingly there is reduction in the congestion cost. During congestion management without and with renewable source units in Case1 the voltage profile at various buses has been shown in Fig 15. It is observed that the voltage profile is within the limits during the congestion management.

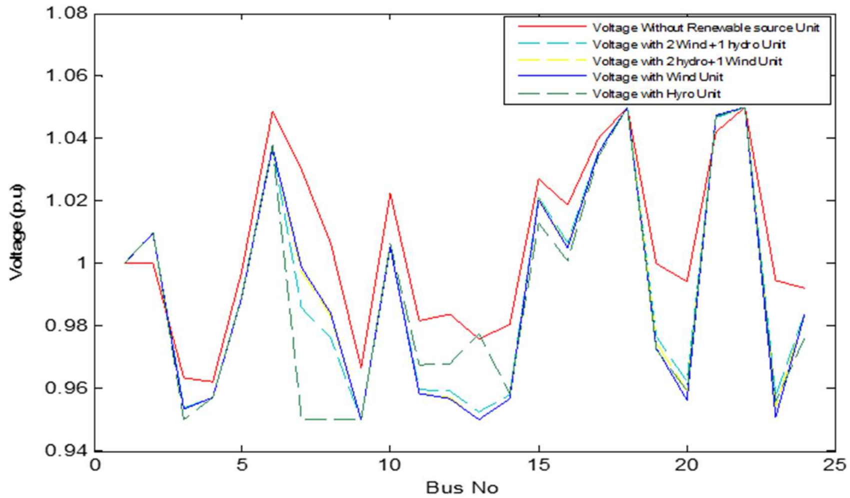

Fig.15 Voltage profile with and without Renewable source Units in Case1 (3-line congestion) of congestion management

5.2 Case2. Two line congestion management

In Case2 study, two lines (15-16 and 14-16) are considered as congested lines. The base power flows on line (15-16) was 226.33 MVA and line (14-16) was 332.84 MVA. The lines flow limits are decreased from 500 MVA to 150 MVA and 300MVA respectively. The congestion management problem has been fixed by based rescheduling. The day-head Pg and new generation schedules Pgn are obtained without and with renewable source. In with renewable source different integrated and non integrated renewable source are used with Wind Units, with Hydro Units, with 1 Hydro+2 Wind Units and with 2 Hydro +1 Wind Units. The up-down generation and generator rescheduling after congestion management are shown in table 4. It can be observed that (8, 13, 16 and 23) units offering lower bids prices and it generation rescheduled up to their ramp limits. The remaining other generators bid prices are made on adjustment.

Table4 Generation schedule with and without renewable energy source units participation in per unit

Gen	2L Congestion Line (15-16) and (14-16) without renewable resource				2L Congestion Line (15-16) and (14-16) with Wind Units			2L Congestion Line (15-16) and (14-16) with Hydro Units			2L Congestion Line (15-16) and (14-16) with 1Hydro+2 Wind Units			2L Congestion Line (15-16) and (14-16) with 2Hydro+1 Wind Units		
	P_g	P_{gn}	ΔP_g^u	ΔP_g^d	P_{gn}	ΔP_g^u	ΔP_g^d	P_{gn}	ΔP_g^u	ΔP_g^d	P_{gn}	ΔP_g^u	ΔP_g^d	P_{gn}	ΔP_g^u	ΔP_g^d
1	1.52	1.52	-	-	1.52	-	-	1.52			1.52			1.52		
2	1.	1.	0.	-	1.5		-	1.			1.			1.		

	52	90	38		2			52			52			52		
7	1.5	2.09	0.59	-	1.5	-	-	1.5			1.5			1.5		
8*	2.4	2.4	-	-	2.513	0.343	-	2.47	.073		2.4			2.4		
13*	2.36	2.36	-		3.65	0.40	-	3.16	.80		3.75	0.50		3.34	0.099	
15	4.5	3.7	-	0.80	3.7	-	0.80	3.7		.80	3.7		0.80	3.7		0.80
16	1.5	1.55	0.05	-	1.55	0.05	-	1.55	.05		1.55	0.05		1.55	0.05	
18*	3.5	3.5	-	-	2.85	-	0.40	3.5			2.85		0.39	2.7		0.80
21	3.0	2.2	-	0.80	2.74	-	0.2595	2.75		.2415	2.75		0.24	2.91		0.085
22	3.1	2.86	-	0.23	3.0	-	0.10	2.41		.6824	3.0		0.10	3.0		0.10
23	3.5	4.3	0.80	-	3.85	0.35	-	4.3	.80		3.84	0.342		4.25	0.75	

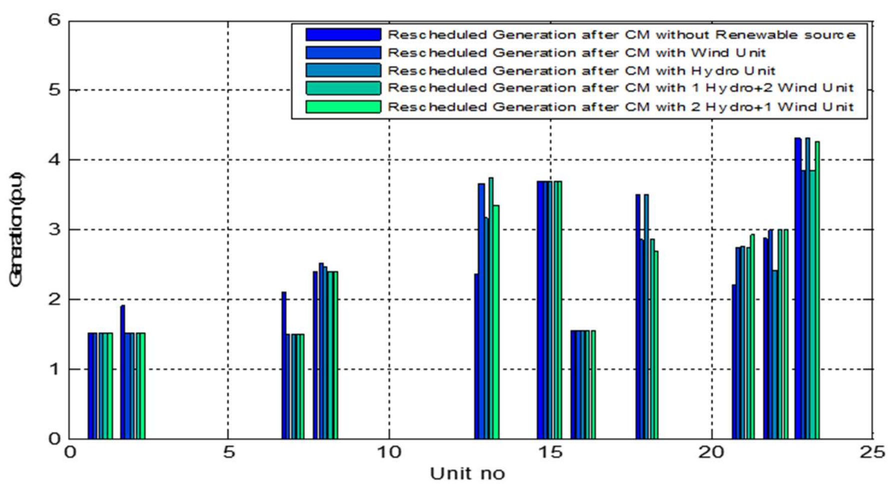

Fig.16 Generators rescheduling for Case2 (2- Line congestion) Congestion Management without and with renewable source

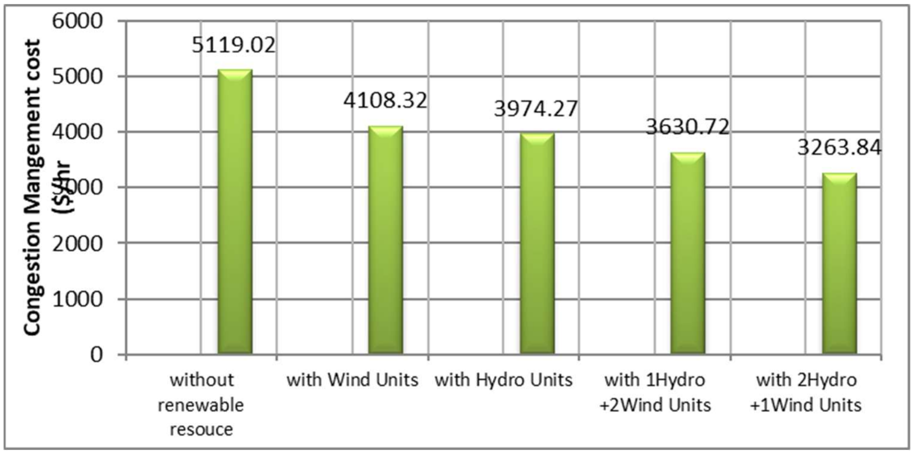

Fig.17 Case2 (2-line congestion) Congestion Management cost of with and without renewable resource

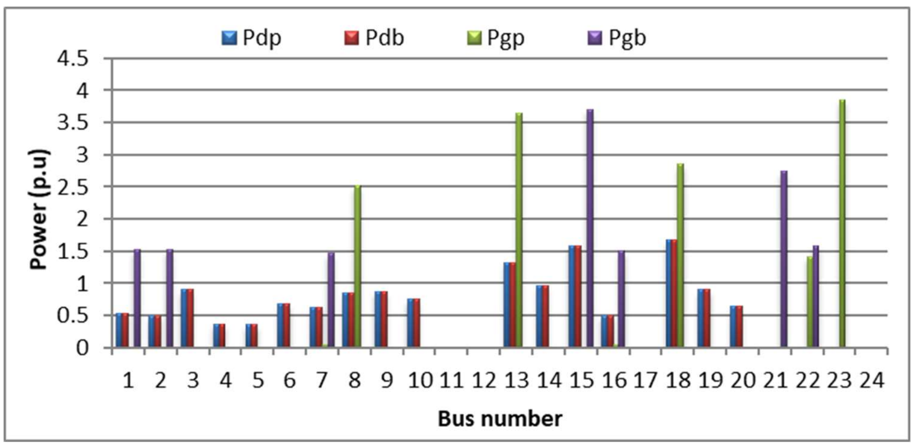

Fig.18 Bilateral and pool power in Case (2-line congestion) with Wind Unit

In Fig16 shown, the rescheduling of generation without renewable source and with renewable source (with Wind Units, with Hydro Units, with 1 Hydro+2Wind Units and 2Hydro+1Wind Units) for 2- line congestion management and minimize the congestion cost. In Case2 (2-line congestion) have been observed that the congestion management cost without and with renewable source are 5119.02 $/hr without using renewable source, 4108.32$/hr with Wind Units, 3974.27$/hr with Hydro Units, 3630.72$/hr with 1Hydro+2 Wind Units and 3263.84$/hr with 2Hydro+1 Wind Units has been shown in Fig.16. It can observed that the Case2 (2-line congestion), the minimum congestion cost are 3263.84 $/hr with 2Hydro+1Wind Units case. The comparison of without and with renewable sources congestion management cost we have save 1010.7$/hr with Wind Unit, 1144.75$/hr with Hydro Unit, 1488.3$/hr with 1Hydro+2Wind Unit and 1855.18 $/hr with 2Hydro+1Hydro Unit.

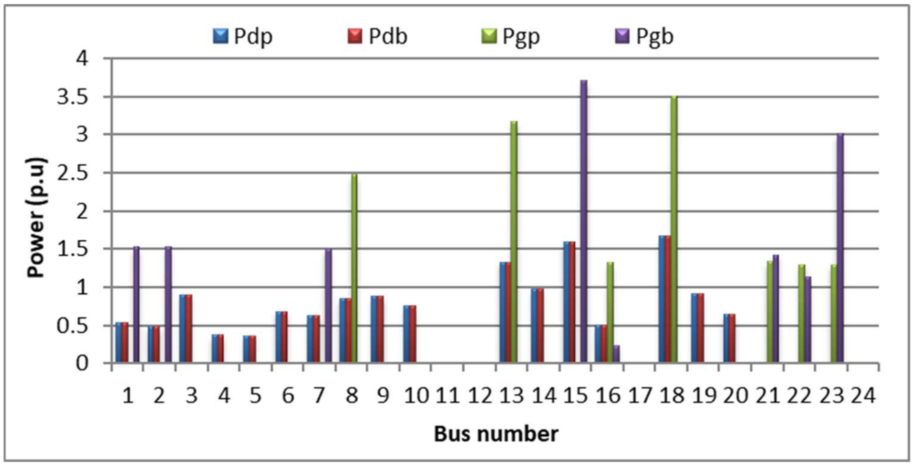

Fig.19 Bilateral and pool power in Case2 (2- line congestion) with Hydro Unit

In Fig.18, Fig19, Fig 20, and Fig21 has been shown, the (pool and bilateral) power demand and generation along with up-down power by with renewable source (with Wind units, with Hydro units, with 1Hydro+2Wind units and with 2 Hydro+1 Wind units) units participating in congestion management for Case2(2-line congestion). The generation up and down of the Case2 (2-line congestion) in congestion management at without and with renewable source have been shown in Fig.22. During congestion management without and with renewable source units in Case2 (2- line congestion) the voltage profile at various buses has been shown in Fig 23. It is observed that the voltage profile is not improved but its in under limit.

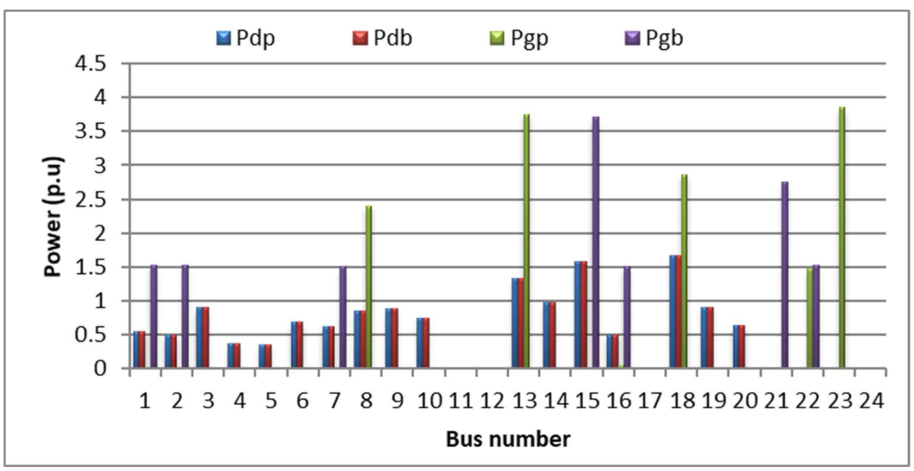

Fig.20 Bilateral and pool power in Case (2-line congestion) with 1Hydro+2Wind units

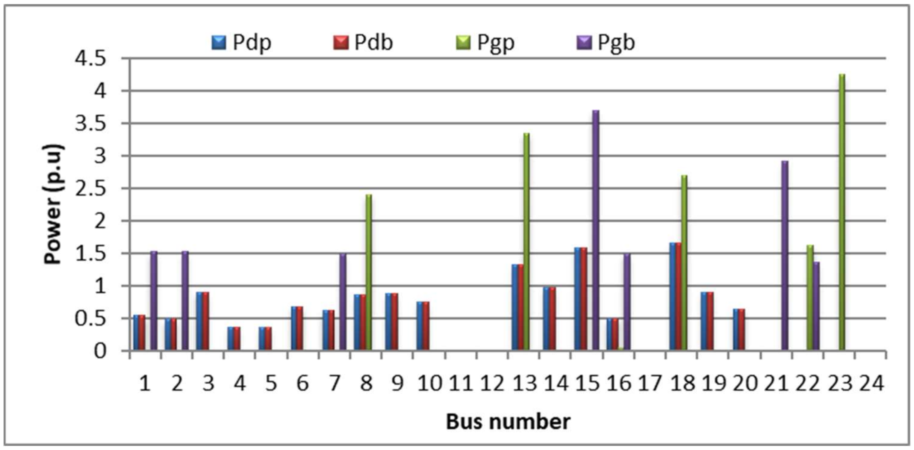

Fig.21 Bilateral and pool power in Case (2-line congestion) with 2Hydro+1Wind units

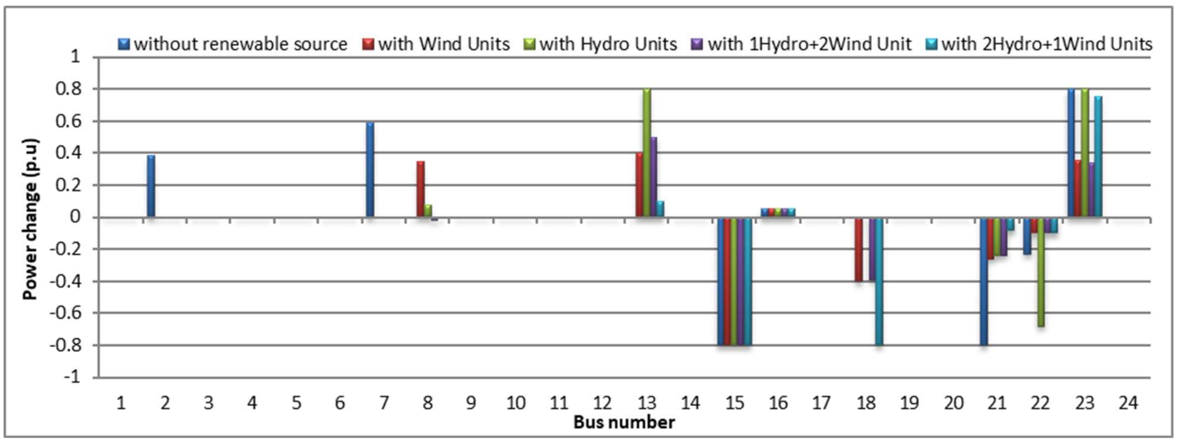

Fig.22 Generation up and down without and with Renewable source at Case2 (2-line congestion) of congestion management

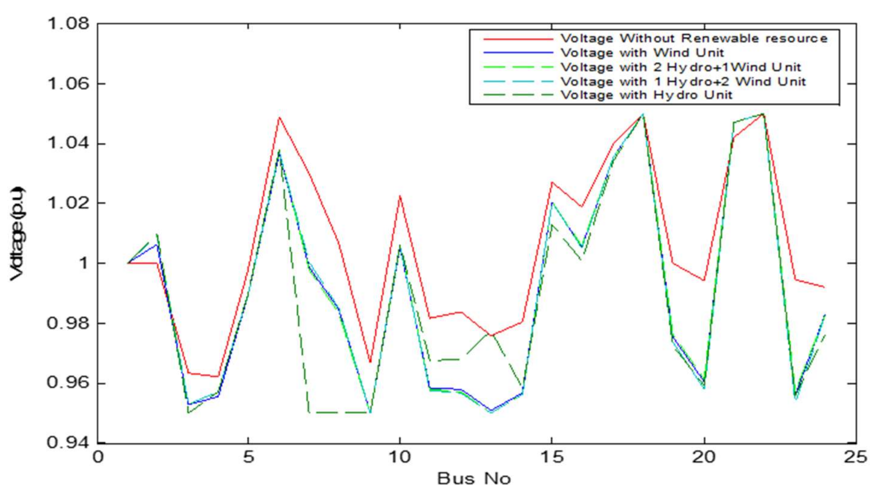

Fig.23 Voltage profile with and without Renewable source units in Case2 (2-line congestion) congestion management

5.3 Comparison of Case1 and Case2 without and with renewable source for congestion management

In Fig. 24, the cost comparison without and with renewable source for Case1 (3-line congestion) and Case2 (2-line congestion) is shown. It is observed that in Case2 (2-line congestion) congestion cost is lower as comparison of Case1 (3-line congestion) at without and with renewable source. Without renewable sources, the congestion management cost are 5119.02$/hr in both Case1 (3-line congestion) and Case2 (2-line congestion). With renewable source, the costs are 4542.42$/hr and 4108.32$/hr in Case1(3-line congestion) and Case2(2-line congestion) at with Wind Units, 4252.89$/hr and 3974.27$/hr in Case1(3-line congestion) and Case2(2-line congestion) at with Hydro Units , 4155.8$/hr and 3630.72$/hr in Case1(3-line congestion) and Case2(2-line congestion) at with 1Hydro+2 Wind Units, and 3715.42$/hr and 3263.84$/hr in Case1(3-line congestion) and Case2(2-line congestion) at with 2 Hydro+1Wind Units. With 2Hydro+1 Wind Units for both Cases (Case1 (3-line congestion) and Case2 (2-line congestion)) congestion cost are observed lower.

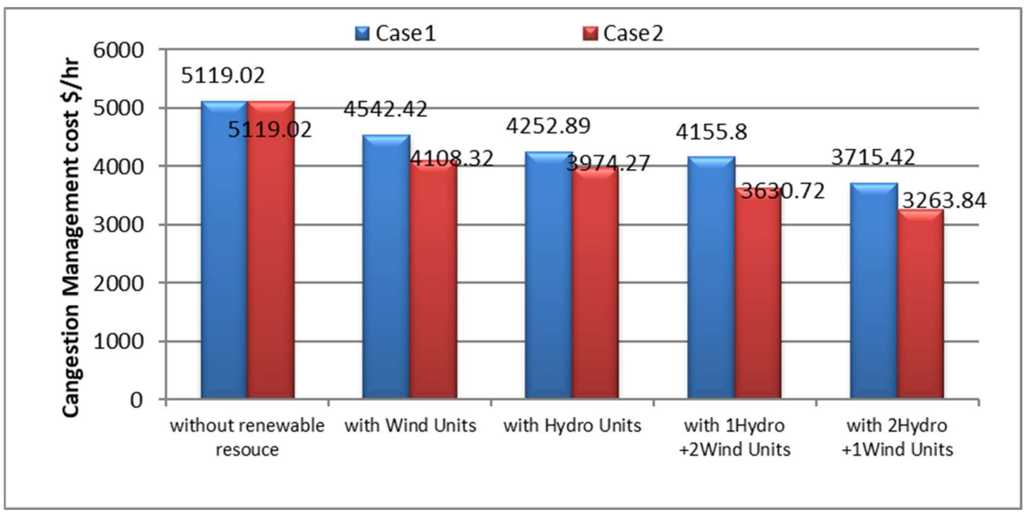

Fig.24 Case1 (3-line congestion) and Case2 (2-line congestion) Congestion Management cost of with and without renewable resource

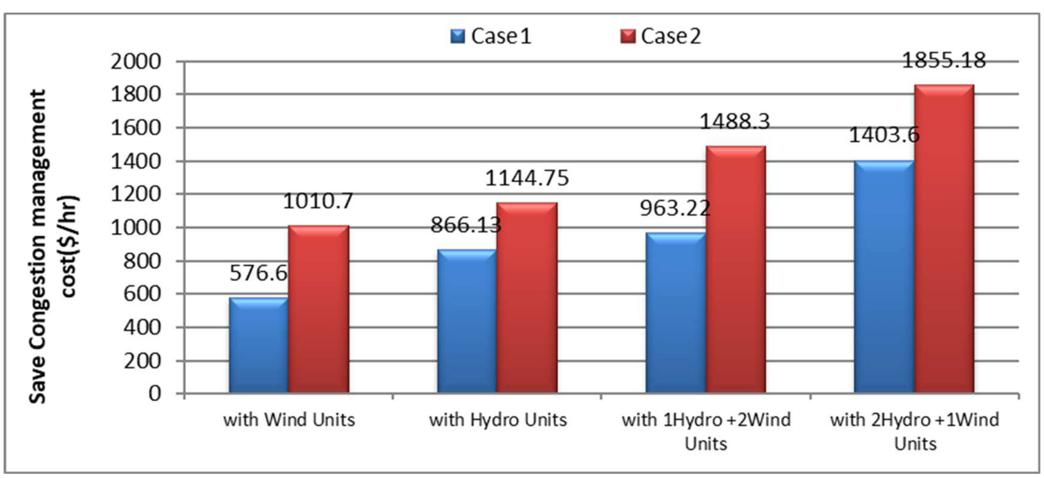

Fig.25 Saving of congestion management cost with Case1 (3-line congestion) and Case 2 (2-line congestion)

In Fig. 25, saving of congestion management cost comparison without and with renewable source is shown. It can be concluded that with 2Hydro+1Wind Units, there is more saving of congestion cost as comparison to Case1 (3-line congestion) and Case2 (2-line congestion). In Case2 (2-line congestion) saving of congestion cost are more as compared to Case1 (3-line congestion) in all renewable combination Units (with Wind Units, with Hydro Units, with 1Hydro+2Wind Units, and with 2Hydro+1Wind Units). In Case1 (3-line congestion) 576.6$/hr and Case2 (2-line congestion) is 1010.7 $/hr saving cost of congestion management with Wind Units. With Hydro Units, saving of congestion management cost are 866.13$/hr and 1144.75$/hr in Case1 (3-line congestion) and Case2 (2-line congestion) respectively. With 1Hydro+2Wind Units, saving of congestion management cost are 963.22$/hr and 1488.3$/hr in Case1 (3-line congestion) and Case2 (2-line congestion) respectively.
The best combination of renewable source are 2Hydro+1Wind Units as saving of congestion cost are 1403.6$/hr and 1855.18$/hr in Case1 (3-line congestion) and Case2 (2-line congestion) respectively. Thus, with significant renewable energy sources, they have considerable impact on managing congestion. In future electricity markets, these sources will have significant share and will play a key role for avoiding congestion and helping the ISO/TSO for better management of the network.

6 Conclusions

This paper presented the use of generator rescheduling to manage congestion while taking into account the contribution of renewable energy sources. Hydro unit performance has been added utilising a piece-wise linear characteristics curve. It is observed that the congestion management cost is reduced in the presence of renewable energy sources. Results have been obtained using a variety of combinations of conventional generating units, hydro, and wind energy.
It is observed that with 2Hydro+1Wind units, congestion cost reduction is more as compared to other cases at Case1 (3-line congestion) and Case2 (2-line congestion). The congestion cost for Case2 (2-line congestion) reduced more as compare to Case1 (3-line congestion) and saving of congestion cost also more for congestion management. The integration of 2 Hydro+1Wind Units are providing best results for minimization of congestion cost of transmission line in Case1 (3-line congestion) and also for Case2 (2-line congestion). The integration of renewable source, Hydro and Wind units play important role for overall congestion cost reduction due to the low operating cost of wind power and hydro units.
Because both have low operating costs and hydro units have a rapid start-up time, the integration of renewable energy sources, hydro and wind units, can play a significant role in the future electricity market. The ISO has a major role to manage congestion with renewable sources integrated into the system taking judicial decisions for their participation and making the electricity market economically more efficient under situations of congestion in the network. This study will help the ISO for taking appropriate decisions effective participation of hydro and wind units in thermal generation dominated system
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