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Power System Planning with Renewables Energy

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***Abstract*—With reference to Power System, the most fundamental system are generation system and transmission system. Generation of power system comes from different sources of generating utilities ranging from hydro, wind, solar, geothermal among others. Power planning entails investment on the electric energy generation and number of lines required to be installed with reference the total energy demand from the consumer side. Investment on energy generation is a key factor that helps in obtaining the suitable size of the plant, the kind of contemporary technology required to be put in place as well as the appropriate timing upon which new plant installation is required to neutralize the deficit in load demand as per the forecasted load within a specific zone. Similarly, in power planning, the number of transmission lines required are determined so that customers receive reliable and sufficient level of power supply despite rising load demand and change in load profile dynamics. The technological improvement in the sector of renewable energy over the recent years has made it suitable alternative for power system planning and expansion. The integration of renewable energy to the existing power grid generates additional power, which takes a reputable position as far as power system planning, and expansion is concerned.**

Keywords—Power System, Power System planning, Renewable Energy, Renewable Resources Integration, AC power flow approach, optimal power flow and Automatic Generation Control.

I. INTRODUCTION

With changing dynamics in industrialization and living style of world populace by embracing technology and technological products, the demand of the electricity has been on the rise. Since time immemorial, the main sources of electric power supply in nations have been based on the national power grids. The construction of power systems and transmission lines are dependent on factors such as distance to the load location, ruggedness of the transmission terrains, maintenance costs against Return on Investments, ROI. Return On Investment also depends the load demand scale.

Power planning with renewable energy integration has been one of the most common remedies to expansion of existing power system with less negative environmental impact. The renewable energy is green source of energy that in most cases emits no or less harmful and toxic gases into the atmosphere. Similarly, the operation cost of renewable energy system is relatively cheaper as compared to other inorganic sources of electrical energy. This is because sources of renewable energy are naturally available freely.

There are three main configurations of renewable energy systems namely; on-grid, off-grid and hybrid. For the On-Grid system, the output generated from the renewable energy source is tied on the grid at common point of connection such as inverter. The On-grid system enables generated power from renewable energy source to used directly when there is high demand as well as to be supplied into the grid whenever there is excess in surplus [1].

Therefore, the essence of grid-tie renewable energy system is designed to serve significantly in reducing the monthly electricity bill as well as reduce over reliance on the national grid system.

In an off-grid system, the system is set to operate on Islanding mode, which is management system that entails configuring, and implementation of the power system at the distribution level to protect sensible and vulnerable loads from power outages. It guarantees continuous supply of electric power even when the main utility collapses [2] [3]. However, the disadvantage of Islanding mode is that in case of fault, power utility company is not liable [4]. The hybrid off-grid system installation is also costly in terms of acquiring storage systems such as storage battery.

In general, the best approach in addressing the issues of power planning is by seeking the intervention of renewable energy sources. As aforementioned, renewable energy sources are environmentally friendly as compared to the counterpart. However, when executing power system planning using renewable energy sources, issues of intermittent and non-dispatchable nature of the renewable energy sources have to be dealt with in a sophisticated manner. Similarly, there is a constrain associated with location of renewable energy establishment. For instance, the transmission lines supplying power remotely from renewable energy plant has to be modified when dealing with expansion planning of the transmission network.

The main objective concerns in power system planning entails economic impact, environmental impact and operations. One of the remedies to this problem has been integration of renewable energy sources. Prevention of system failure, reliability and shedding of loads, power system planning has to be optimally implemented. According to Avnish Paul et al. such systems can be mathematically defined using non-linear equations [5]. The system of equations' real and imaginary variables represents nodal voltages. The number of nodes is a half the number of equations. Also, these equations consisting of real and imaginary parts are quadratic in their formation. Using these equations, the planner is able to obtain loading conditions of the lines. The power loss and bus voltages can also be generated and defining the limits of each. In power flow analysis, generator and load power are known values.

II. LITERATURE SURVEY

A. Power Flow Approach In Ac System

Expansion planning of the transmission of power can be done in a deregulated power system through various ways. In a stable state, the power system with N nodes can be mathematically implemented using 2n power flow expressions as shown below.

$$P_{G(i)} - P_{L(i)} = P_{N(i)} \qquad (1)$$

Where;

$$\begin{cases} P_{G(i)} = node\ i\ generator\ active\ power \\ P_{L(i)} = node\ i\ Load\ active\ power \\ P_{N(i)} = node\ i\ Active\ injection\ power \end{cases} \qquad (2)$$

But Node active power injection is given by the expression shown below.

$$P_{N(i)} = V_i \sum V_j Y_{ij} \cos(\theta_i - \varphi_{ij}) \qquad (3)$$

Where;

$$\begin{cases} Y_{ij} = Admittance\ between\ connected\ nodes\ i,j \\ \varphi_{ij} = Phase\ angle\ between\ connected\ nodes\ i,j \end{cases}$$

(4)

Similarly, reactive power expression is given as shown below.

$$Q_{G(i)} - Q_{L(i)} = Q_{N(i)} \qquad (5)$$

Where;

$$\begin{cases} P_{G(i)} = node\ i\ generator\ reactive\ power \\ P_{L(i)} = node\ i\ Load\ reactive\ power \\ P_{N(i)} = node\ i\ reactive\ injection\ power \end{cases} \qquad (6)$$

But Node reactive power injection is given by the expression shown below.

$$Q_{N(i)} = V_i \sum V_j Y_{ij} \sin(\theta_i - \varphi_{ij}) \qquad (7)$$

Therefore, solving equation (3) and (7) gives unknown variables of 2n unknown variables. For easier analysis, the system is simplified algebraically using equation of the vector as shown below.

$$= \{g(x,u) = 0 \qquad (8)$$

The meaning of vector representation are;

$$\begin{cases} u = controllable\ variables\ with\ m - components \\ x = Dependent\ variables\ with\ 2n\ components \\ g = the\ power\ flow\ equation (3\&7) of\ 2n \end{cases}$$

(9)

B. Optimal Power Flow

The analysis of optimal power flow of the system incorporates economic dispatch in conjunction with power flow. The main objective is to reduce the cost function while considering realistic equality as well as inequality constrains on the power flow of the system. The equality constraints entails power balance on the bus (real and reactive), the set point of generator voltage and the area MW interchange. Similarly, the inequality constraints involves transmission components (lines, transformers and interface flow limits), the MW threshold of the generator, and capability curves of reactive power generated from the generator. Lastly, controls available incorporated MW output of the generator as well as phase angles and power transformer taps. As much as efficiency of power flow should be maximum, the cost of generation and distribution should be maintained low. To achieve this mode of operation, the variation of real and reactive power of the generator with reference to the load demand is one of the key area that is considered so as to minimize on cost of fuel. Economic dispatch (Optimal Power Dispatch) is one of the fundamental consideration in power flow planning [5].

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III. METHODOLOGY

The statement of the AC maximum power flow problem was formulated in this section. Basically, economy is the main aim for optimization of power. The economy can be analyzed in terms of operating cost per hour denoted as F as expressed below.

$$F = \sum V_i(P_{G(i)}) \qquad (10)$$

But from equation (8), the substitution makes equation (10) becomes;

$$F = \sum V_i(P_{G(i)}) = F(x,u) \qquad (11)$$

Therefore, from equation (11), the operating cost per hour is a function of active power generated from the generator. The system for power planning has the following known parameters;

$$\begin{cases} \text{Load and generation location} \\ \text{Magnitude of the load and generated units} \\ \text{Availability of units} \\ \text{Load profile} \\ \text{Dispatch pattern} \end{cases}$$

Basing on the given reliability criteria, the power system planner can come up with the design optimization whose transmission cost are minimum. The planner's main aim is to achieve the suitable power flow in the midst technical and economic constraints. The practice is usually done on the deregulated power system. Generation and distribution of the deregulated power system is modified to operate economically and reliably as opposed to the traditions power system. With deregulation power system, the improvement in the generation and distribution of power maximizes on the efficiency and reliability on the pre-existing traditional power system.

Another aspect in power planning can be implemented through automatic voltage control. Nevertheless, automatic voltage generation forms a fundamental component in power planning when it works in conjunction with optimal power dispatch solutions. The normal load demand varies from time to time which my resulting to change in system's frequency. System frequency is vulnerable to changes due to imbalance of generation and load demand. In the same light, it is not easy to establish load through analysis of load forecast. Therefore, this calls for a system in place, Automatic Generation Controller so as to bring sanity in the system's frequency as well as assuring reliable power flow as per the load demand. Therefore, despite the varying load conditions, the system typically operates at the nominal frequency due to correction measure by Automatic Generation Controller. In other words, the Automatic Generation Controller automatically adjusts the output of the generator so as to restore absolute scheduled value of the interchange power.

IV. CASE STUDY

For the implementation of Power Planning system with renewables, a case study was done on a research done by Avnish Paul et al. titles “Power System Planning With Renewable Resources Integration” [5]. In their research work, the researchers discussed in depth methods of AC power flow approach, optimal power flow and Automatic Generation Control. The purpose of the experimental simulation was to find out how system frequency can be maintained while minimizing the cost of operation and fulfilling optimal power flow constraints. The simulation was for power planning was done using combination combinations of generator sources as highlighted below.

- Thermal, Thermal and Thermal combination.
- Thermal, Wind and Thermal combination.
- Thermal, Solar and Thermal combination.
- Thermal, Solar and Wind combination.

A 6-bus system was analyzed with their nominal voltages and types as shown in table 1 below.

Table1: Bus types and ratings

Bus name	Type	Nominal kV
Bus_1	PQ	138
Bus_2	PQ	138
Bus_3	PV	138
Bus_4	PQ	138
Bus_5	PV	138
Bus_6	Slack	138

a) Thermal , Thermal and Thermal Combination (TTT)

In this system, all generators are thermal. The system was constructed in PSCAD software as shown in the figure below.

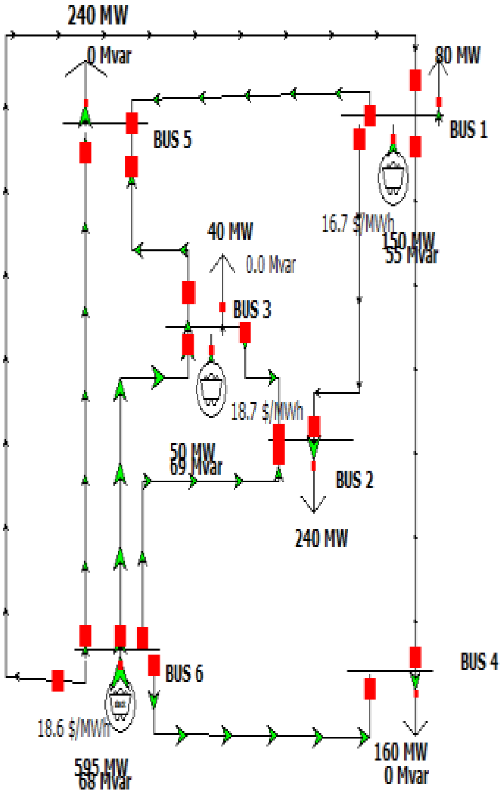

Figure 1: 6-Bus system with Thermal Thermal Thermal (TTT)

The results obtained were recorded in table 2, 3 and 4.

b) Thermal , Thermal and Wind Combination (TTW)

In this system, there are two thermal generators in combination with Wind generator. The system was constructed in PSCAD software as shown in the figure below.

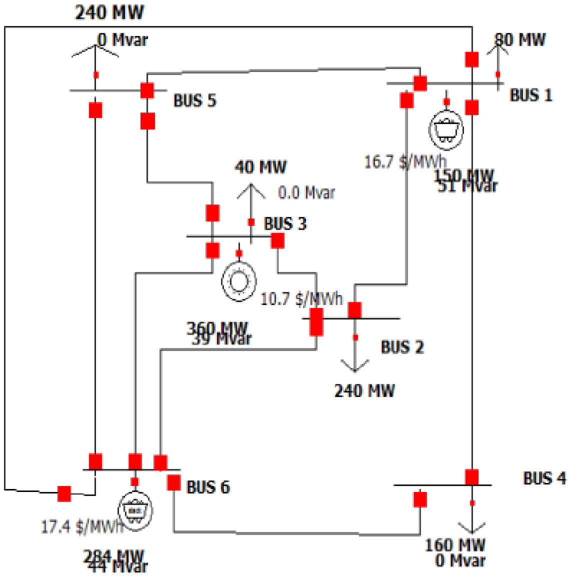

Figure 2: 6-Bus system with Thermal Thermal Wind (TTW)

The system was simulated and the results obtained were recorded in table 4

c) Thermal , Thermal and Solar Combination (TTS)

In this system, there are two thermal generators in combination with solar generator. The system was constructed in PSCAD software as shown in the figure below [5].

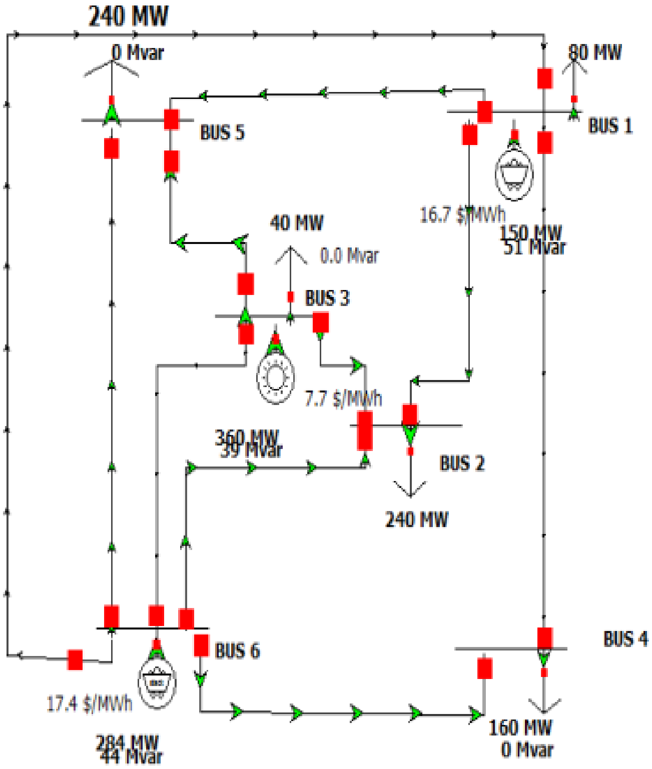

Figure 3: 6-Bus system with Thermal Thermal Solar (TTS)

The system was simulated and the results obtained were recorded in table 4

d) Thermal , Thermal and Solar Combination (TWS)

In this system, there are three combination thermal, wind and solar generators. The system was constructed in PSCAD software as shown in the figure below.

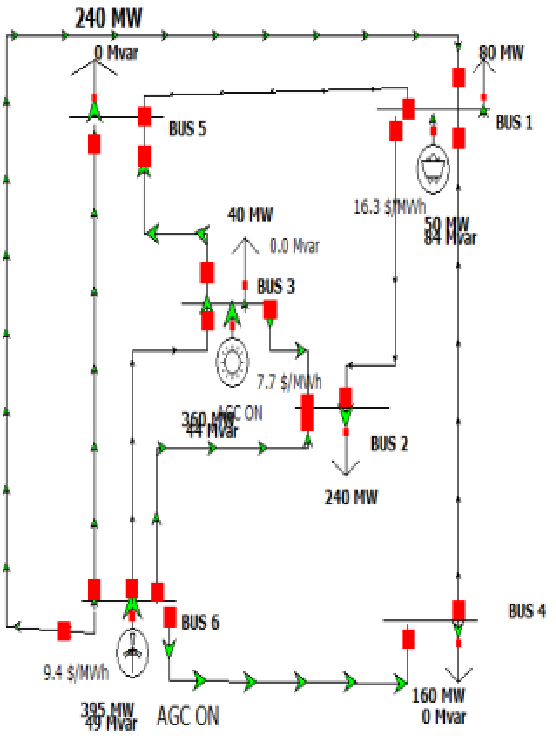

Figure 4: 6-Bus system with Thermal Wind Solar (TWS)

The system was simulated and the results obtained were recorded in table 4

V. ANALYSIS AND RESULT

The voltage profiles of for the buses in the Thermal Thermal Thermal (TTT) system obtained were summarized in the table below.

Table 2: Bus simulated voltages for TTT system.

Bus name	**Volts (kV)**	**Angle Deg**	**Load MW**	**Gen MW**	**Gen MVar**
Bus1	143.5	-12.4	80	150	55.4
Bus2	130.9	-21.1	240		
Bus3	143.5	-11.2	40	50	68.9
Bus4	142.2	-9.09	160		
Bus_5	133.7	-19.5	240		
Bus_6	143.5	0.00		594.	67.8

Generators are directly connected to bus1, bus3 and bus6. Similarly, the results obtained from generator records for Thermal Thermal Thermal (TTT) system is as shown in table 3. The results highlights generated power, hourly cost of operations, initial cost and profit.

Table 3: Results for Generator records of TTT system

Name of the bus	**Gen MW**	**Hourly cost of operation ($/hr)**	**Initial cost**	**Profit ($/hr)**
Bus 1	150	2975.32	2975.32	-180.11
Bus 3	50	1784.82	1784.82	-853.09
Bus 6	594.7	11063.33	11063.33	18.07

All systems of power system planning with different renewable sources were recorded in table 4 below.

Table 4: Results of different systems

System	**Normal Load**		**15% increased load**	
	Total cost ($/hr)	***Total cost ($/MWh)***	***Total cost ($/hr)***	***Total cost ($/MWh)***
TTT	15824	18.63	18239	19.25
TTW	12531	17.37	14763	18
TTS	11460	17.30	13703	18
TWS	8114	9.37	9365	9.76

The results in table 4 were analyzed graphically using bar graphs as shown in the figure below.

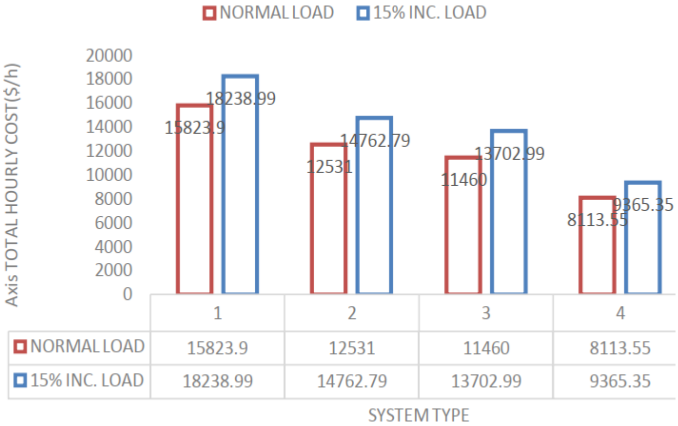

Figure 5: Hourly cost variations of different systems

On the same note, the variations of Optimum Power Flow (OPF) on different systems were represented graphically as shown below.

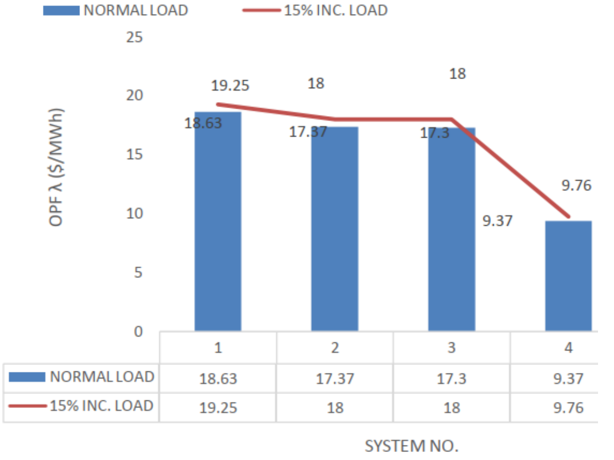

Figure 6: Variations of Optimum Power Flow (OPF) on different systems

From the results obtained and the graphical analysis, it was noted that operation of TTT system is more expensive than systems integrated with renewable sources. For instance, in terms of operation, the TTT system operation has posted highest value of operation as compared to others. Similarly, the Optimum Power Flow of the TTT system is highest. When a thermal generator source was replaced with wind generator or solar generator, the operation cost and Optimum Power Flow reduced responsively. When the system was made of TSW system, the operation cost and Optimum Power Flow reduced drastically. The reason for low operation cost of power system with more renewable source is by the fact that major generating part of the system is fuel free.

VI. CONCLUSION

Power system planning with renewables was analyzed theoretically and used case study for results analysis. Different sources of renewable energies and how they are integrated on the existing grid system with aim of minimizing operation cost were discussed. For power system planning, three different generator sources were used in combination of renewable and thermal generators. It was noted that power system made of purely thermal generators is not economical and compared to the system with integrated renewable energies.

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