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Designing of Solar PV Plant, Wind Energy System and load flow analysis of grid power integration

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Abstract— Electricity plays a vital role in the country's development. One Grid One Nation concept empowers the country with various electricity resources. Energy through different sources have their own characteristics and the load flow analysis are different. If the Grid is Integrated with various sources which may have distortions like harmonic, reactive power issues etc. A work to mitigate the grid disturbances needs to understand load flow analysis, with data of applied voltage, active and reactive power and use devices to reduce the distortions and reactive power to maintain grid stability.

Index Terms— Green Energy, Harmonic distortion, Power Grid, Load flow analysis, Solar energy, Photovoltaic cell, Hybrid System etc.

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1 Introduction

This document gives a brief idea and analysis of grid integration through various different sources. Nowadays, Indian power grid is energized with conventional and non-conventional sources, India has a single combined power grid which energized through Solar, wind, thermal, hydropower, nuclear power. All Sources integrate their generated energy into grid. To get energy through different source it possesses different generation systems and algorithms. Energy generated through a different medium with different sources creates a relational disturbance.

Countries are widely interested to develop green energy in their periphery, developed countries are already developed their infrastructure and they are independent of the energy crisis. They are already energized their nation with a single grid structure. Generated power supply through different sources can directly feed into grid through the electrical utility substation. The generating stations like thermal and hydropower running with generator or turbines create harmonic distortion. When these distortions occur, it is considered as lost in the power system. The solar plant generation varies with the radiation which also creates distortion because whenever the system fed supply into the grid it must have a higher voltage than the grid voltage. Grid intake power supply through different sources with different sizes of the plant and have different voltage levels create a huge disturbance. This article shows basic understanding with the load flow analysis and harmonic equilibrium.

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Generally, Countries are empowering their grid supply supporting green energy aka renewable energy. Countries are readily looking to set new renewable energy plants and to avoid the setup of non-conventional sources of energy. The commercial and industrial sectors are accepting the conventional source of energy and promoting green energy. Industrial sector promoting to install solar plants or wind plants for their captive use. If they do not have the infrastructure to set up the plants in their region so they can go for an open-access model.

Some of the commercial and industrial players are accepting hybrid model which is more promising then the grid-connected solar PV plants, grid-connected solar plant has a limitation, it cannot work if the grid supply is cut whereas, in the hybrid system, we can energize load through the other sources like battery storage system or diesel generator. Through this, consumers can get an un-interrupt power supply.

2 Current Scenarios

Generally, Countries are empowering their grid supply by supporting green energy aka renewable energy. Countries are readily looking to set new renewable energy plants and to avoid the setup of non-conventional sources of energy. The commercial and industrial sectors are accepting renewable energy and promoting green energy. Industrial sector promoting to install solar plants or wind plants for their captive use. If they do not have the infrastructure to set up the plants in their region so they can go for the open-access model.

Some of the C&I players are accepting hybrid model which is more promising then the single grid-connected solar PV plants, Solar Plant has some limitations that it cannot work if the grid supply is cut whereas, in hybrid system, we can energize load through the other sources like battery storage system or diesel generator. Through this customer can get an un-interrupt power supply. The generating power from thermal and hydropower stations produces stable supply but the carbon footprints are also producing simultaneously. To reduce the carbon footprints, switch to non-renewable energy to renewable energy is the only and promising solution.

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2.1 HYBRID PLANT

The system which has two or more than two sources of energy is termed as Hybrid System. There are many types of hybrid systems is existing in the market.
According to the presence of conventional energy sources: Hybrid systems with conventional sources – mostly the systems, using conventional sources are more powerful and responsible; Hybrid systems without conventional sources – as a general, that kind of systems are relatively low power and/or tend to be more irresponsible. If the systems are correctly designed and if energy storage is provided, then it would be able to generate sustainable energy [1]. Refer the Figure 1 for the hybrid system constitutes grid, solar, wind and non-renewable sources of energy hybrid system. These types of the system make C&I sector reliant and independent.
A hybrid renewable PV–wind energy system is a combination of solar PV, wind turbine, inverter, battery, and other additional components. A number of models are available in the literature of PV–wind combination as a PV hybrid system, wind hybrid system, and PV–wind hybrid system, which are employed to satisfy the load demand [2].

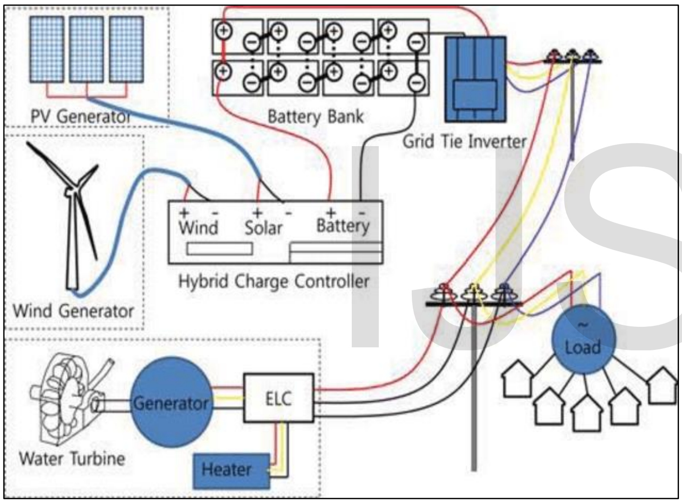

Figure 1 Hybrid system [1]

- Solar PV Plant + battery storage + Grid
- Solar PV Plant + battery Storage + DG
- Wind Energy System + DG + Grid

2.2 Grid Integration

When the power generating utility fed their supply into the grid is termed as grid integration. As the producer and user are connected through the same channel. Industrial and customer are connected through the substation while rooftop solar PV is connected with the grid, while large scale solar PV utility connected through the grid with step up peripherals [2].

As we've shown within the above image solar PV plant, Wind energy system, and Bioenergy system, Thermal and non-renewable sources are feeding power into the grid, and users also are connected to the equivalent grid. [3] [4].
Since thermal and hydropower station is unendingly energizing grid whereas the star and wind are dependable on nature however these sources are renewable in nature and overabundant accessibility. These supplies are seeming to become the first source as if we have an advance storage facility.

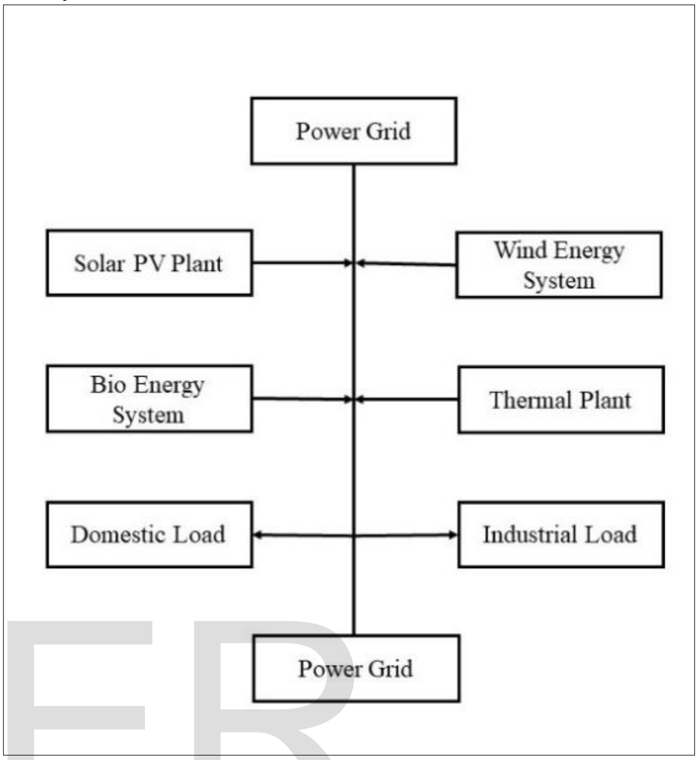

Figure 2 Grid Integration with various sources

3 METHODOLOGY AND FRAMEWORK

3.1 System Designing

Here we design Solar PV plant of capacity 1 MW and whereas wind energy system having the capacity of 1 MW bio diesel generator is also generating capacity of about 2 MW. See the tables (Table: 1, Table: 2, Table: 3) hereinbelow for sizing of renewable energy generating systems.

PV Module capacity	370 Wp
Total No. of modules	3120 (Nos.)
Total Capacity (kWp)	1154.4
Inverter Maximum Input	1200 kW
Inverter output (kW)	1000 kW
No. of modules in a string	16
No. of Strings in parallel	195
Voltage DC	640 V
Output Voltage	400-415 V
Supply	3 Phase
Frequency	50 Hz

Table: 1 Solar Array Matching

WES Output (Induction Generator)	1000 kW
Output Voltage	400-415 V
Power Factor	90%
Efficiency	95%
Poles	4
Operating Voltage Angle	1.3

Table: 2 Wind Energy System Sizing

Bio Diesel Generator	2000 kW
Output Voltage	400-415 V
Power Factor	85%
Efficiency	95%
Poles	4
RPM	1500
Rotor Type	Round Rotor

Table: 3 Bio-Diesel Generator

Here we have seen the system sizing parameters those we are considering in this analysis research, when these three generating stations are operating simultaneously then we check the load balancing figures throughout the grid The parameters and the rated output of PV module [5], Inverter [6], Generator [7], Transformer [8] are taken from the leading manufacturers data sheet.

4 MODELLING AND SIMULATION

As we consider decided parameter shown on Table: 1,Table: 2,Table: 3 for the Solar PV plant WES and Bio Diesel Genset, we put formulated data in the software name ETAP (version 16.0) and we will see the following curves between power, current and voltage. The selection of modules in single strings calculation was based on solar array matching principles and gathered meteorological data from NASA solar power calculator. The tilt angle of the PV Panel will be 23^0 as latitude. Because we have considered the location in India at 23.319806°, 77.358385°.

4.1 Modelling

Calculation for tilt angle of the Solar PV Cell

The orientation of modules will be in south, because as per the convention if the plant location lies in northern hemisphere the orientation will be in South whereas, the plant lies in southern hemisphere then the orientation will be towards North direction.

a) The altitude of the sun when it is over the equator (Ye) for a specific latitude is:

$$Atitude\ of\ the\ Sun(Ye) = 90^0 - Latitude\ (in\ degrees)$$
$$= 90^0 - 23.31^0$$
$$= 66.69^0$$

b) To calculate the tilt angle, we use the altitude of the sun and the following formula

$$Module\ Tilt(\beta) = 180^0 – 90^0 - Atitude\ of\ the\ Sun(Ye)$$

$$= 180^0 – 90^0 - 66.69^0$$
$$Module\ Tilt(\beta) = \sim 23^0$$

The most appropriate tilt angle is to align photo voltaic module as per latitude, because we are considering the tilt angle as per the equator plane. The angle between 15^0 to 25^0 considered as good because this is the optimum tilt angle for solar PV module.

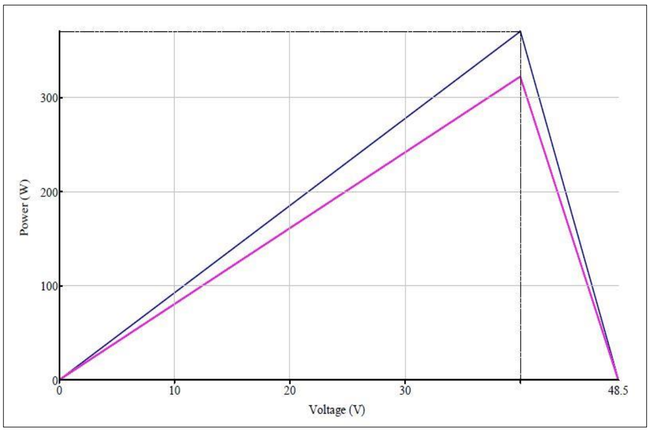

Figure 3 Power curve for the solar photo voltaic cell

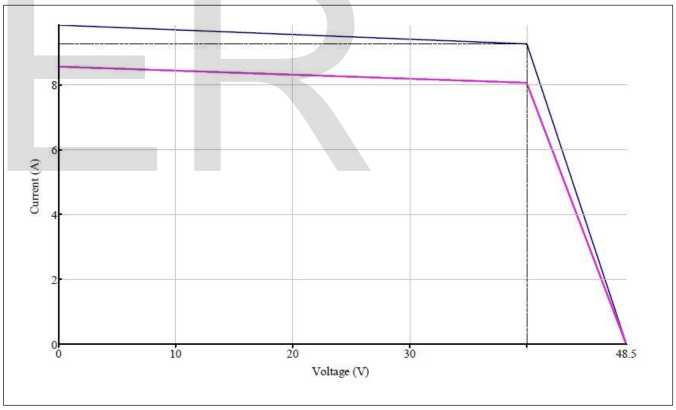

Figure 4 I-V Curve for solar photovoltaic cell

As we have seen above, the relation between power and voltage in Figure 3, the power of the module at rated voltage is above than 300 W as per module data sheet provided by the manufacturer. Whereas the relation between current and voltage shows the maximum current rating at knee point.

Designing of Wind Energy System:

The wind energy system is another pillar of renewable energy, to mount windmill it necessary to calculate wind speed of the actual reason, A well-designed wind invariably has an honest calculation of air current wind and therefore the ramp wind.

The wind energy system is available as a complete package with wind mill with generator (Swing type) from the

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manufacturer's end. Here we have considered the 1 MW composite wind energy system and we considered the average wind speed is 10 m/s. Considered wind factors are shown in Figure 5.

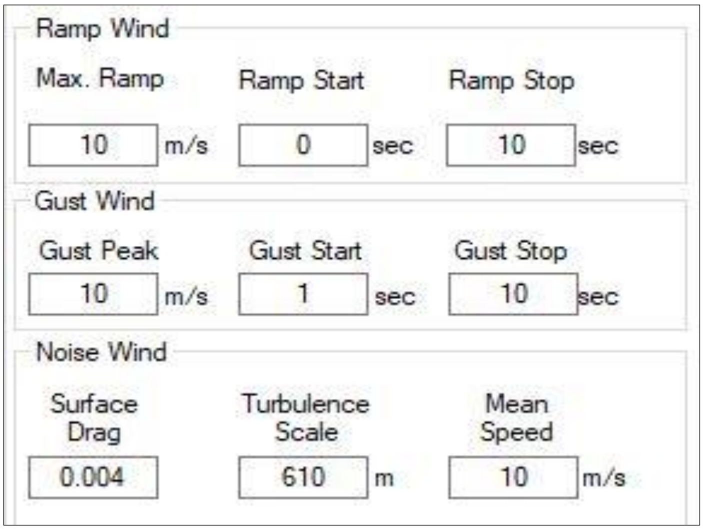

Figure 5 Considered wind factors

While planning the wind energy system we've thought of the subsequent knowledge of Ramp wind, Gust wind, and Noise wind. Gust wind plays an outstanding role within the wind energy system that's why we have thought of the info from the free accessible platform. [9].

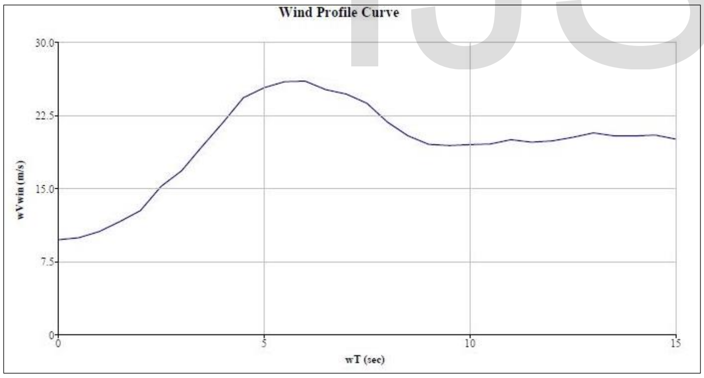

Figure 6 Wind Curve

Designing of Bio-Diesel Generator

As the system is totally dedicated to green energy, we have decided to provide backup solar PV system with Bio Diesel generator capacity of 2000 kW (rated output) [7].
In the designed Bio diesel generator, we have tried to maintain the harmonic spectrum as low as possible (in Figure 7) which maintains the system life cycle.The Bio generator system fueled with biodiesel. the flaxseed oil and genus Jatropha oil are considered as appropriate fuel for biodiesel generator, this may increase the demand for biodiesel, which improves the production of flaxseed and genus Jatropha which could facilitate to boost the farmer's economy.

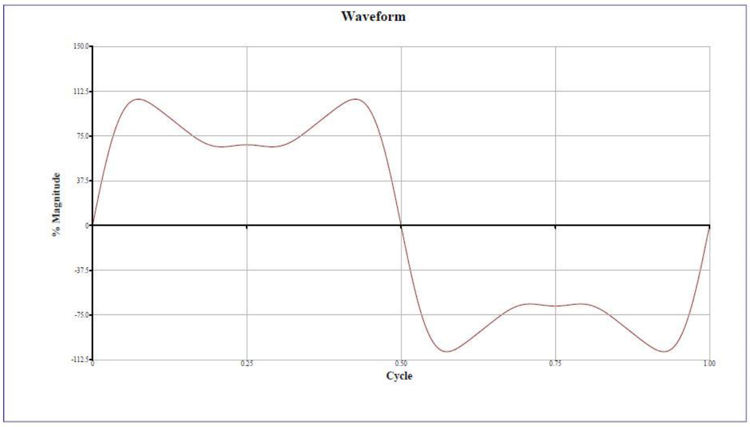

Figure 7 Generator Harmonic Waveform

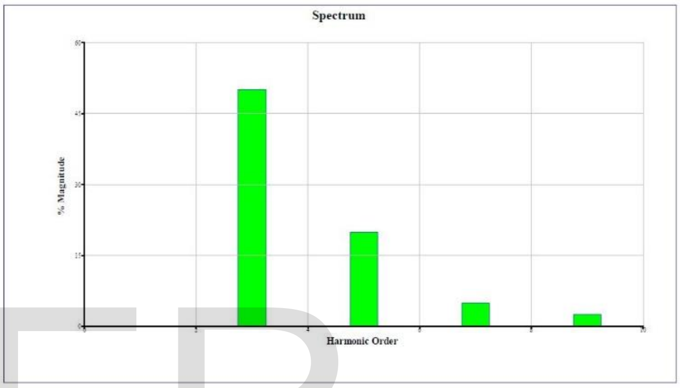

Figure 8 Generator harmonic spectrum

As we have seen in the Figure 8 the generator harmonic waveform is identical and there are no distortions in the waveform which harm the system and in the Figure 8 generator harmonic spectrum also shows the harmonic order in the respect of magnitude which shows the system balancing condition.

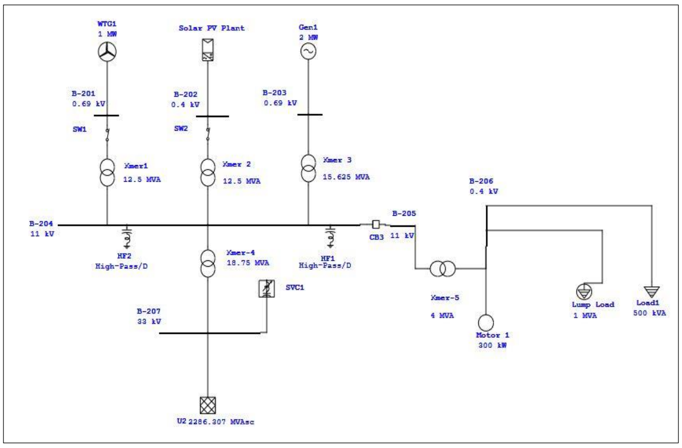

Figure 9 System Design

In the Figure 9, we have seen that wind energy system, Solar PV Cell System and Bio - Diesel Generator is connected with 0.4 kV Bus, the output from all three entities will be in AC and

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having a voltage is 400 V or 0.4 kV. The bus carrying 0.4 kV voltage supply is further connected with step up transformer [8] having capacity 12.5 MVA, 0.4 kV/11 kV and the output of the transformer is connected with 11 kV bus. 11 KV bus supply is connected to another step-up transformer of capacity 18.75 MVA and 11/33 kV. The step-up transformer is connected to grid supply.
As we 11 kV is the standard supply using for distribution in urban areas and supply further stepdown to 0.4 kV and release for the consumption.
As shown in Figure 9, 11 kV supply line is connected with 2 MVA stepdown transformer having voltage range 11/0.4 kV and then the supply is further connected to load. Three different natures of load considered in the designed system.

1. Industrial Load
2. Lump Load
3. Distribution load/Spot load

1. Industrial Load
Industrial load considered as elite group at the consumer point of view because they drawing high current to operate industrial motors of different type for different purpose. Three phase motors are operating in at 0.4 kV.
2. Lump Load
Lump load which is generally a simplified transmission network is also drawing power of about 1 MVA. This is the transmission line which usually carries power supply at distant.
3. Distribution load
The distribution load is the load which is directly connected to the distribution lines at different locations of the city. The distribution lines are carrying supply through the distribution substation supplies electricity to home consumers and commercial consumers.

4.2 Simulation

The whole proposed system is designed over the platform of software named ETAP. This is the widely accepted simulation software in the field of energy sector (in research and in commercial sector). For the load flow analysis there are several other software's but this platform is available in the organized way.

After design the SLD in the software we have assigned all required data of equipment like PV System, transformers, generator, wind energy system etc. The designed parameters are taken from the renewed manufacture's datasheet. Grid system and parameters are designed as per Indian Standards. After the completion of the system design we got several results in the simulation which we will discuss in the next part.

5 Result

As per the simulated reports we have considered the following results for analysis.

1. Optimal power flow
2. Transformer load analysis.
3. Overall load flow analysis

1. Optimal Load Flow Analysis
The optimum study of load flow offers the best level of service for electrical power plants to meet the demands of the entire transmission network.

2. Transformer load analysis.
Load flow analysis through the transformer shows the working performance of the transformer at required load of required load of domestic and commercial.

3. Overall load flow analysis
The analysis of load flow is to determine the steady-state operational conditions of the power system for real power and voltage conditions of a given load and generator. Once we have that information, together with energy losses, we can easily calculate real and reactive power in all branches.

Bus			Initial Voltage	
ID	kV	Sub-sys	% Mag.	Ang.
B-201	0.690	1	100.0	0.0
B-202	0.400	1	100.0	30.0
B-203	0.690	1	100.0	0.0
B-204	11.000	1	100.0	30.0
B-205	11.000	1	100.0	30.0
B-206	0.400	1	100.0	30.0
B-207	33.000	1	90.0	0.0

Total Number of Buses: 7

Figure 10 Bus Load Flow

Generation Bus			
ID	kV	Type	Sub-sys
B-201	0.690	Mvar/PF Control	1
B-202	0.400	Mvar/PF Control	1
B-203	0.690	Voltage Control	1
B-207	33.000	Swing	1

Figure 11 Generation bus flow

As shown in the Figure 11 Bus ID (B-201) is connected wind energy system while B-202 is connected with the output of the central inverter and having the output voltage is 400 V. The Bio-diesel generator is connected with B-203 and Grid supply (swing) is connected with B-207 with the high voltage rating 33 KV. Total seven buses we have considered in this system and four busses are connected with the generating sources. The voltage is flowing the particular angle as shown in the Figure 10.

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Load Flow				
ID	MW	Mvar	Amp	% PF
B-204	1.000	-0.484	691.7	-90.0
B-204	0.850	0.000	911.7	100.0
B-204	0.000	0.000	0.0	0.0
B-201	-1.000	0.489	43.4	-89.8
B-202	-0.850	0.003	33.2	100.0
B-203	0.000	0.000	0.0	0.0
B-207	-0.289	-1.392	55.4	20.3
B-205	2.139	0.902	90.5	92.1
B-206	2.139	0.902	90.5	92.1
B-204	-2.139	-0.902	90.5	92.1
B-205	-2.133	-0.849	2489.2	92.9
B-204	0.289	1.396	18.5	20.3

Figure 12 Optimal load flow analysis

As we have seen the outcome of optimized load flow analysis, as we considered the grid network to be bilateral, the higher correlation indicates that the power flow to the load in the opposite direction.

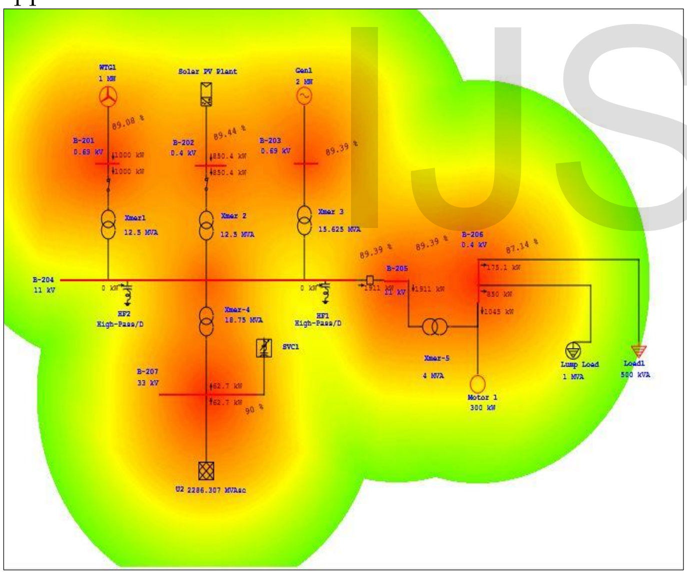

Figure 13 Colour zone load analysis

The red zone showing that the heavy power is flowing through the buses whereas yellow shows the lower intensity of power flow. The green zone shows the receiving end i.e. customer end.

Transformer		Rating					
ID	Phase	MVA	Prim. kV	Sec. kV	% Z1	X1/R1	
Xmer1	3-Phase	12.500	0.690	11.000	8.35	13.00	
Xmer 2	3-Phase	12.500	0.400	11.000	8.35	13.00	
Xmer 3	3-Phase	15.625	0.690	11.000	10.00	20.00	
Xmer-4	3-Phase	18.750	11.000	33.000	7.00	18.60	
Xmer-5	3-Phase	4.000	0.400	11.000	7.15	8.50	

Figure 14 Transformer Load flow analysis

The transformer load flow analysis shown in Figure 14 Transformer Load flow analysis and all transformers are in 3-Phase and the value of impedance and reactance shown in the above figure. The calculated data and terms used as per BIS standards.

Load Flow				
ID	MW	Mvar	Amp	%PF
B-204	1.000	-0.484	1043.6	-90.0
B-204	0.850	0.000	1372.4	100.0
B-204	0.000	0.000	0.0	0.0
B-201	-0.999	0.495	65.5	-89.6
B-202	-0.850	0.006	49.9	100.0
B-203	0.000	0.000	0.0	0.0
B-207	-0.062	-1.448	85.1	4.3
B-205	1.911	0.948	125.3	89.6
B-206	1.911	0.948	125.3	89.6
B-204	-1.911	-0.948	125.3	89.6
B-205	-1.899	-0.847	3444.9	91.3
B-204	0.063	1.458	28.4	4.3

Figure 15 Overall load flow analysis

The overall load flow analysis considered all overload situations and open circuit and short circuit conditions.

6 CONCLUSION AND DISCUSSION

As we have seen that the difference between the optimal load flow and overall load flow analysis. We have also seen that transformer load flow analysis during all load connected. The transformer plays a key role while maintaining the load flow between the bus and the various other loads.We have connected the generation source like a windmill, Solar PV plant, and biodiesel generator, and the output is connected through the step-up transformer and further connected with the bus. The bus voltage is maintained as per the transformer output voltage.

Two harmonic filter is connected with the bus to maintain the harmonic distortion which binds the disturbance in the bus due to heavy load. The grid is having swing characteristics which are

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used as sink when the other generation unit is working, when the solar system or other generation unit is not working then the grid supplies power through conventional sources of energy.

This is one of the best ways to decentralize the existing system and provides the supply through other green sources to the grid. When the grid is energizing through the different sources then the grid is not only depending on the conventional sources only. As the country is moving towards the one grid one nation plan and already India is leading country to energize grid through renewable sources. The designed system is simulated in the worldwide accepted software ETAP, the simulated reports will be available through the given link or can be provided on request through the given mail address.

The grid system we have designed is bilateral in nature and the power flows towards the source to sink. As we have seen that the grid is energizing through the different source but at the same time the load is connected through the grid is consuming power. This means the grid supply is very unstable in nature but at the same time the instability can be cured through the compensators which create the unwanted disturbances in the grid.

To maintain the grid stability, we need to consider the harmonic filters which maintain the disturbances among the busses and we need to maintain the reactive power as well. We have considered these aforementioned issues in our designed system and tried to avoid these circumstances which we already shown in the figures.

As the energy sector is moving towards the smart grid which is having more advanced technology where the system performed the load flow and acts as per demand. The system conjugates energy from different sources and provides the optimal energy per demand. From this analysis, we can easily understand the load condition and which bus is under exiting and which is overloading. The load can be balanced from the overloaded bus to underloaded bus which helps in balancing the load in grid supply.

7 Future Prospectus

Here we have opened the window to other new researches or scholars to integrate more load and various energy sources to the grid and perform the analysis of grid stability. There are many things to explore like, designing the transformer and perform optimal load flow and harmonic distortion analysis.

Other aspects for the detailed analysis of bus carrying the power and consider the aluminum bus bars or copper bus bars and then analyze the grid stability. Variation of load in between commercial, domestic, lump, and spot load with different sources or different sources with different load characteristics at real-time and operation time analysis. Grid stability is comprising of various factors and vast aspects of research and innovation. It would be great if new scholars take this analysis into another level and propose the algorithm of efficiency.

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