Comparison & Simulative Analysis of Low Voltage Distribution System (LVDS) with High Voltage Distribution System (HVDS) Towards Performance Enhancement

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Abstract: An electric power distribution system is the last stage in the delivery of electric power; it carries electricity from the transmission system to individual consumers. Distribution substations connect to the transmission system and step down the transmission voltage to medium voltage. The work is focused on bringing about the comparative analysis on the outcomes at the load points in the low voltage distribution system and the high voltage distribution system. The results concluded enhancement in the quality issues associated with the low voltage distribution system while designing of the High voltage distribution system. The losses in the voltage and current profile were reduced to bring about enhancement in the power availability in the loading points by 3 %. To further analyze the performance of HV distribution system with renewable energy resources the hybrid system of solar and wind generation systems were developed and then were integrated with the LV system first and then with the HV system. The study again concluded improvement in the power by 2.7% reducing the losses in the voltage and current profiles. The HV system loading was also identified to reduce the effects on the 11KV high voltage distribution line. Thus it can be inferred from the study that Implementation of high voltage distribution system (HVDS) for consumers will result in reduction in losses, increase in energy saving and improve voltage profile. The adoption of HVDS makes the system more reliable and thus, reduces the number of outages. The chances of unauthorized connections and theft of energy are reduced.The restructuring of existing low voltage distribution system (LVDS) as HVDS presents one of the best technically feasible and financially viable method for providing reliable and quality supply to consumers.

Key words: LV system, HV system, THD, Renewable energy resources

I. INTRODUCTION

Electricity is an important infrastructure for the growth of the Indian economy. Accelerating economic growth will depend on a financially and economically viable energy sector capable of attracting new investments.

Expanding capacity in the manufacturing sector largely depends on the credibility of the customer, broadcasting and distribution companies. Generally, electricity is produced in power plants located in places away from consumers. It is then delivered to consumers via an extensive transmission and distribution network. The current electrical grid is by its nature an alternating current (AC). This distribution system starts as a primary circuit exiting the substation and ends as a secondary circuit entering the consumer meter. 220 kV electrical power is transmitted to the periphery through a three-wire three-phase overhead line system, and this power is then received by the primary substation, further reducing the voltage level to 66 kV.

II. LITERATURE REVIEW

IssahB.Majeed et al. [1] In this document, the HVDS and LVDS concepts are evaluated with respect to system performance. This is achieved by examining the system losses in HV and LV distribution networks in radial AC distribution systems. The challenges associated with system losses may require network conversion from the LV network to the HV network. As a result, the operating costs in the optimized HVDS are reduced and the annual savings with activated losses increase.

Erwin Normanyo et al. [2] This paper presents a technique used to convert an existing low voltage distribution system (LVDS) into a high voltage distribution system (HVDS) in radial networks. HVDS optimization is demonstrated using linear programming techniques in the MATLAB Optimization Toolkit. The results of a test application explain the methodology. The proposed optimization technique estimates the optimal number of unit transformers in the HVDS.

Tiago SoaresVítor et al. [3] This paper presents voltage regulation in distribution networks, which refers to the main objective of keeping customer voltages within an acceptable range under all load conditions. This function was carried out by the Volt / Var control, a strategy that coordinates the voltage regulators and reactive power controls to ensure proper system operation. To solve these problems, intelligent systems are built that provide a computationally efficient optimization engine. With that in mind, this chapter introduces Volt / Var control, from basic concepts to advanced topics. It lays the foundation for a comprehensive optimization framework and features Volt / Var optimization as a key tool to further improve system operations goals.

Ahmadi et al. [4] This paper explores the possibility of using data provided by smart meters to understand load characteristics. Loads are modeled as voltage-dependent elements to increase the accuracy of Volt VAR (VVO) optimization techniques for distribution networks. The proposed framework is able to optimally control capacitor banks, voltage regulators and on-load tap-changers (ULTC) for the day's operational planning. The results show that under certain load conditions in a radial test system, losses can be reduced by up to 40% and the total demand can be reduced by up to 4.8%. The effect of the charge voltage dependence is also demonstrated by analytical simulations.

III. OBJECTIVE

The work here is indented to achieve the following key objectives from the SIMULATION performed on the MATLAB software:

- The designing of low voltage distribution system and high voltage distribution system keeping the grid voltage 11KV and the distribution voltage (ground to phase) to be approximately 230 V.
- Analyzing the two systems for their performance in terms of the quality analysis at the loading points calculating the THD% and peak outcomes at the point.
- The further integration of the system with renewable energy resources fed from variable inputs and studies the effects on the LV and HV system.
- The overall analysis is intended to bring an enhancement in the output loading parameters by achieving a reduction in the losses.

IV. METHODOLOGY

The model has been developed in MALAB/SIMULINK environment. It is a matrix language with control flow instructions, functions, data structures, inputs / outputs and object-oriented programming functions. It has the following main features:

- High level language for scientific and technical computer science
- Desktop environment for exploring, designing and solving iterative problems
- Graphs to display data and tools to create customized graphs
- Applications for curve adaptation, data classification, signal analysis, control optimization and many other tasks
- Complementary toolboxes for various technical and scientific applications
- Tools to create custom applications for the user interface
- Distribution options at no cost for sharing MATLAB programs with end users

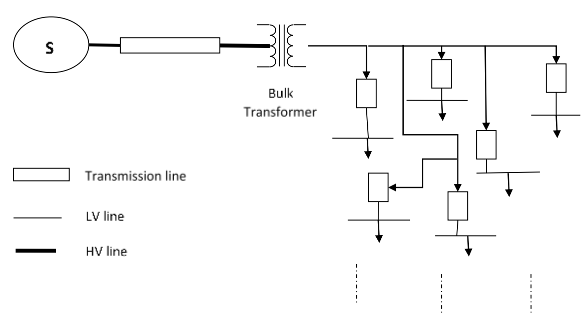

Fig. 1 Low Voltage distribution system MATLAB/Modeling Block Diagram

In the Low voltage distribution system, large capacity transformers are provided at one point and the connections to each load is extended through long LT lines. The distribution bulk transformer selected at the HV line is of 315KVA rating converting the 11KV voltage into the 230V line to ground voltage to be sufficiently available at the load terminals. The fig.1 depicts the block diagram depicting the LV system designing in the SIMULINK. The dark line shows the high tension 11KV line from the grid source and the light lines show the 230 volt phase to ground voltage line. The transmission system made use of only one transformer for distribution over a large radius.

This long length of low tension lines is causing low voltage condition to the majority of the consumers, power theft by hooking the lines, unauthorized connections and high technical losses. These losses can be eliminated by taking some precautions. And thus, it is necessary to focus on technical losses as well as on commercial losses and it can be achieved by using HVDS method for distribution.

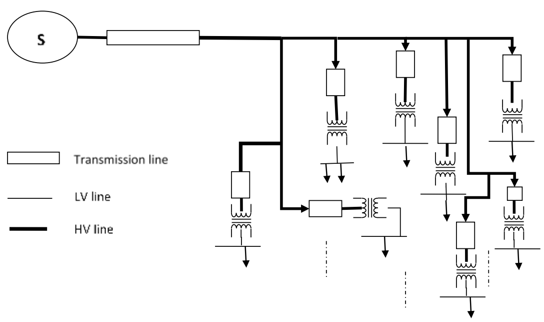

Fig. 2 High Voltage Distribution system MATLAB/Modeling Block Diagram

Figure 2 is the system implemented in the MATLAB software showing the high voltage distribution system. The simulation made use of small transformers of 5KVA to 63KVA rating just before the loading points. The figure illustrates that the high tension run up to the loading points where it is then step down to the required 230 V phase to ground voltage to achieve the load performance. The system showcases more high tension line running across than low tension line as depicted by dark and light lines respectively. To reduce distribution losses, to improve quality of supply and also to prevent theft of electrical energy, high voltage distribution systems (HVDS) are implemented.

The main purpose of using high voltage for distribution is to reduce the theft of energy and decrease in unauthorized connection as the (Low tension) LT lines are virtually eliminated and even short LT lines required will be with insulated aerial bunched cables (ABC). This makes direct tapping very difficult and thus, increases the authorized connection and further faults are totally eliminated which improves the reliability. The designed system is to reconfigure the existing low voltage (LT) network as high voltage distribution system. Each 11kV feeder which substation branches further into several subsidiary 11kV feeders to carry power close to the load points.

The analysis of these low voltage and high voltage distribution system was further extended to analyze the stability and quality issues associated when the feeding is received by the renewable energy resources as well.

A. Modeling of hybrid system

Various modeling techniques are developed by researchers to model components of HRES. Performance of individual component is either modeled by deterministic or probabilistic approaches. This chapter discusses the basic modeling structures of solar energy system, and wind energy system along with modeling of PSS controls.

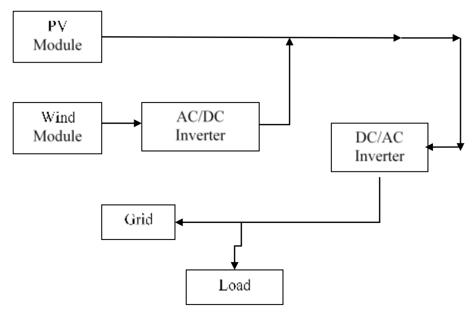

Fig. 3 Proposed Hybrid energy system topology

B. THD calculation for quality studies

The distortion level has been studied that concludes the quality output at the loading points. The distortion level has been carried by calculating the FFT (Fast Fourier Transform) of the voltage and current waveforms available at the load terminal. The system has been provided with the variable inputs namely irradiation and temperature at the solar panels offering the variation in the climatic factors at different regions. The THD calculation has been carried out for studying the initial quality issues with the output at the loading points. The following equation has been used to carry out the calculations:

The finite, or discrete, Fourier transform of a complex vector with n elements is another complex vector Y with n elements:

$$Y_k = \sum_{j=0}^{n-1} \omega^{jk} y_j,$$

Where ω is a complex nth root of unity:

$$\omega \doteq e^{-2\pi i/n}.$$

From the FT spectrum we can calculate THD (total harmonic distortion) of the given signal.

$$\text{THD \% of fundamental} = \frac{\sqrt{\sum_{h=2}^{25} Q_h^2}}{Q_1} \text{X100}$$

V. RESULTS

Low voltage distribution system and high voltage distribution system are two basic configurations of the electrical power distribution system that are being analyzed for their loading parameters assessment in this work. The LVDS is characterized by a high capacity transformer at a load centre. This transformer supplies multiple customers through long low voltage (LV) lines such that is inclusive of the high voltage (HV) lines such as 11kV are the primary distributors being used in the models implemented in the MATLAB/SIMULINK environment.

The system with low voltage distribution was modeled with field data to exhibit the characteristics of a typical network. In this design, 315 kVA transformer for the distribution. The level of enhancement as a result of the optimization process on voltage profile and system losses on the HV distribution network has been carried out. This discussion thus establishes an understanding in this regard.

The work has been carried out by focusing on the comparative result analysis on the basis of following cases:

Case 1: Study conducted for load terminal analysis in the distribution systems

Case: 2 Analysis of 11KV transmission line to study the effects due to loading

This paper discusses how high voltage distribution systems (HVDS) can be a better system used in distribution networks than the currently used distribution system (Low Voltage Distribution System, LVDS). The proposed change of the system into the new configuration is done by replacing a large-capacity distribution transformer with some smaller-capacity distribution transformers and installed them in positions that closest to the load. The use of high voltage distribution systems will result in better voltage profiles and fewer power losses.

With this aspect the analysis from the non-technical side, the annual savings and payback periods on high voltage distribution systems will also be the advantage. Analysis of voltage, current and power waveforms shall indicate the level of enhancement by changing the supply configurations in the MATLAB/SIMULINK software.

Case 1: load terminal analysis in the distribution system

This case has discussed about the electrical parameters and their quality available at the loading points in both low voltage and high voltage distribution system. The graphs depicts the three phase AC voltage and current available along with the associated harmonic distortion levels in them.

The active and reactive powers are also shown to study on the power recovered due to reduction in the losses of the system.

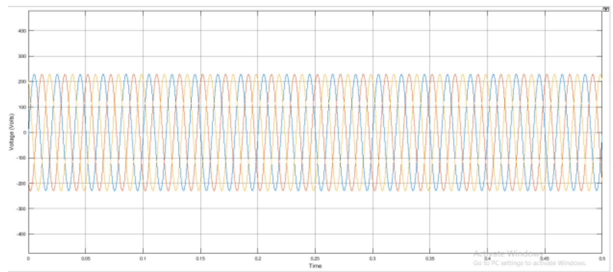

Fig. 4 Voltage available at the load points in HV distribution system

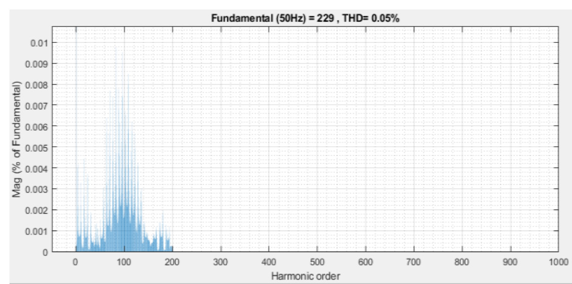

Fig. 5 THD% calculation of voltage available at the load point in HV system

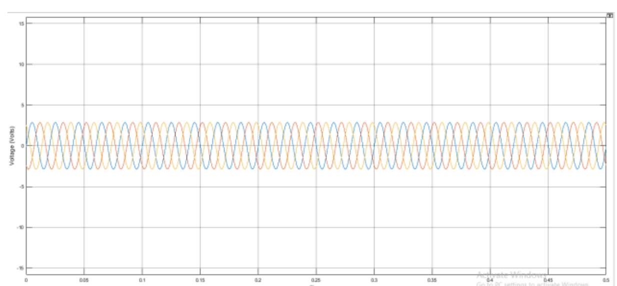

Fig. 6 Current at the load points in HV distribution system

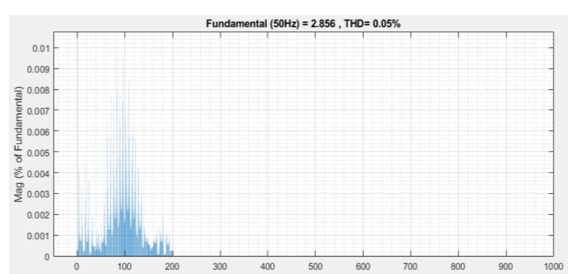

Fig. 7 THD% calculation of current in HV system

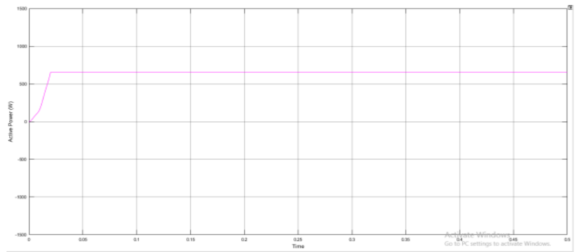

Fig. 8 Active Power waveform at the load points in HV distribution system

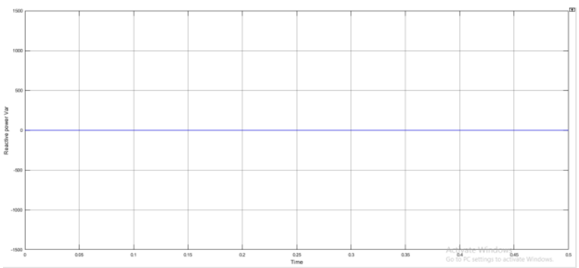

Fig. 9 Reactive Power waveform at the load points in HV distribution system

The HV system analysis at the loading point shows that the voltage of 229 V has a distortion level of 0.05% and the current available at the load is approximately 2.88 A with the total harmonic distortion percentage of 0.05%. The system designed with various loads at high voltage distribution level shows that the active power available is 654W.

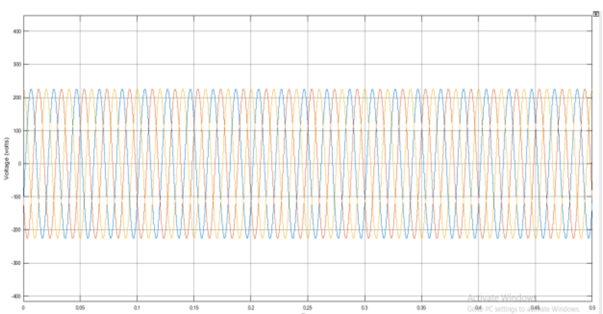

Fig. 10 Voltage available at the load points in LV distribution system

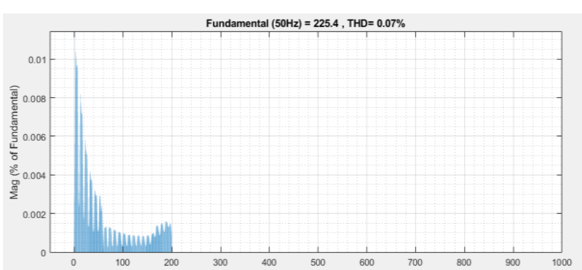

Fig. 11 THD% calculated in the voltage of LV system

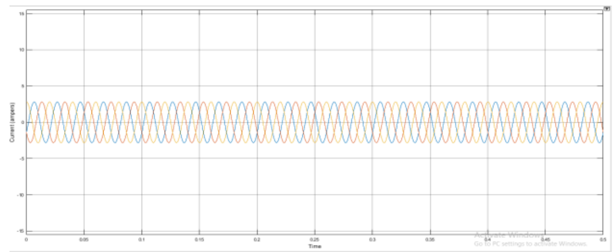

Fig. 12 Current at the load points in LV distribution system

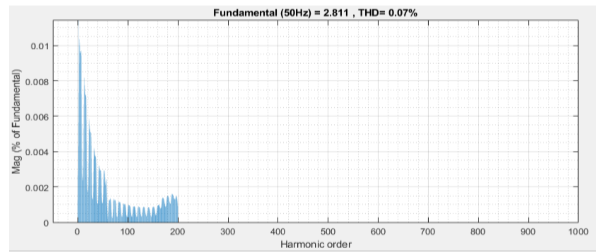

Fig. 13 THD% calculated in the current of LV system

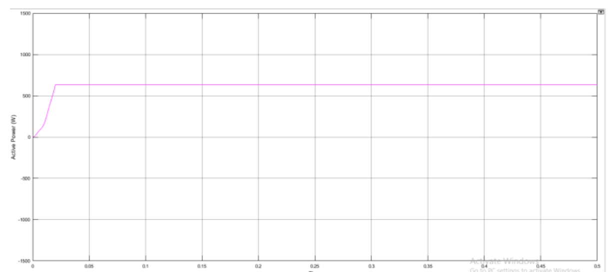

Fig. 14 Active Power waveform at the load points in LV distribution system

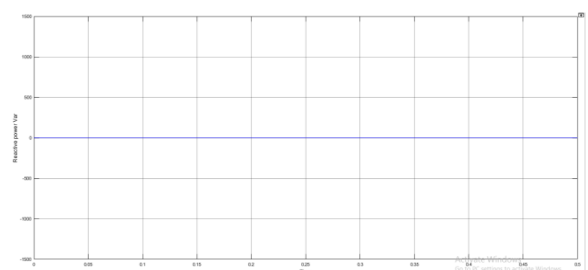

Fig. 15 Reactive Power waveform at the load points in LV distribution system

The LV system analysis at the loading point shows that the voltage of 225.4V has a distortion level of 0.07% and the current available at the load is approximately 2.811 A with the total harmonic distortion percentage of 0.07%. The system designed with various loads at low voltage distribution level shows that the active power available is 633.7W.

Case: 2 Analysis of transmission line effects due to loading

Power systems deliver energy to loads that perform a function. These loads range from household appliances to industrial machinery. Most loads expect a certain voltage and, for alternating current devices, a certain frequency and number of phases.

The analysis was carried out for loads connected through LV or HV distribution system. The presented results confirm the effectiveness of the proposed approach, which could be assumed as a very useful tool in the design and analysis of a power generation system

For stability study, we need analyze the stability of a system including a power transmission line as well and constant power loads. We need to analyze the system stability from the ac side which in our work we have calculated by studying the effect on the voltage line of 11KV due to loading in different distribution system. The objective is achieved by calculating the THD% in the voltage in both the cases.

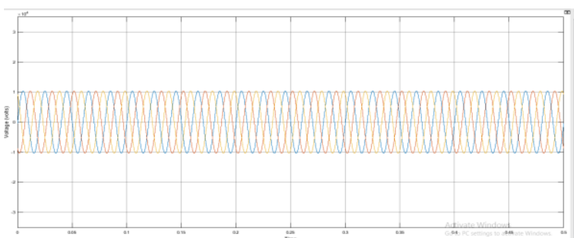

Fig. 16 Transmission line voltage in the 11KV line for HV distribution system

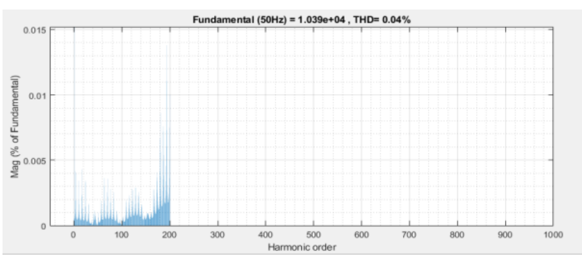

Fig. 17 THD% reflected in the high voltage 11KV distribution line due to HV system loading

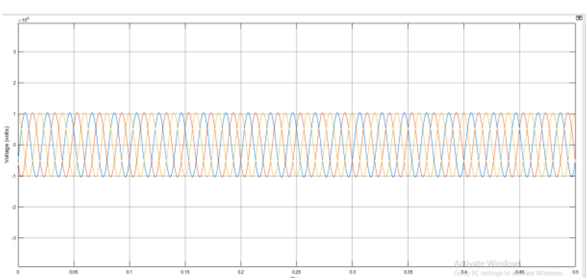

Fig. 18 Transmission line voltage in the 11KV line for LV distribution System

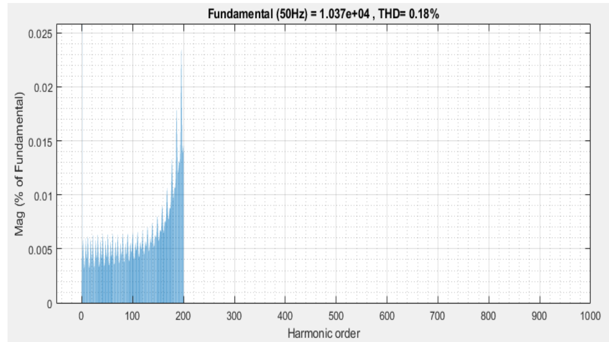

Fig. 19 THD% reflected in the high voltage 11KV distribution line due to LV system loading

The system analysis confirmed the effectiveness of high voltage distribution system than low voltage distribution system in respect of the THD% reflected on the high voltage line as well due to loading. The distortion in HV system was found to be less 0.18% than that of the LV system which was 0.22 in the voltage waveform.

A. Validation

This work discusses how high voltage distribution systems (HVDS) can be a better system used in distribution networks than the currently used distribution system (Low Voltage Distribution System, LVDS).The work done on the HV and LV system has been validated in this segment. The table 5.1 depicts the outcomes from the distribution system. The enhancement in the active power output due to these systems has been depicted in the figure. The red graph depicts the active power available at the load bus in the LV distribution system where as the green graph is indicative of the active power at the load terminal in case of HV distribution system.

$$\%\ increase\ in\ active\ power = \frac{new\ AP - old\ AP}{old\ AP}\ x\ 100$$

$$= \frac{654 - 633.7}{633.7}\ \text{x}\ 100$$

= approx 3.1%

The gap between the red and green graphs shows the power recovered by reducing the losses. The power has enhanced by 3.1 % in the HV distribution system.

Table 1: Comparative analysis of electrical parameters from the two systems.

S no.	Parameters studied for the comparative study	Parameters at the low voltage distribution system	Parameters at the high voltage distribution system	Improvement detection

1	THD% of voltage at the load line	0.07 %	0.05%	Reduced by 0.02
2	Peak Value of voltage recovered	225.4 V	229 V	3 V recovered
3	THD% of current at the load line	0.07%	0.05%	Reduced by 0.02
4	Magnitude of current available at the terminal	2.811 A	2.88 A	Reduced current loss
5	Active Power available (Watts)	633.7 W	654 W	3.1% increase in power
6	Reactive Power	0 Var	0 Var	-
7	Effect of loading on 11KV line in terms of THD% in voltage	0.22%	0.04%	Reduced by 0.18

It is concluded from the table 5.1 that the use of high voltage distribution systems will result in better voltage profiles and fewer power losses. From the non-technical side, the annual savings and payback periods on high voltage distribution systems will also be the advantage.

B. Integration with the renewable energy systems

1 HV and LV system study with grid interfaced solar wind energy systems at the load line

The system in this case has been integrated with the hybrid solar wind energy systems. These energy systems are dependent on the natural factors such as wind, irradiation level by sun etc which are highly variable in the environment. Thus their output might carries within themselves the effect of these parameters. The high voltage distribution system and low voltage distribution system has been studied by the interfacing of these resources for driving the loads.

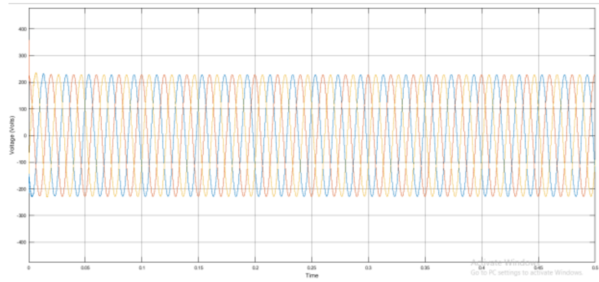

Fig. 20 Voltage available at the load points in HV distribution system with renewable energy resources

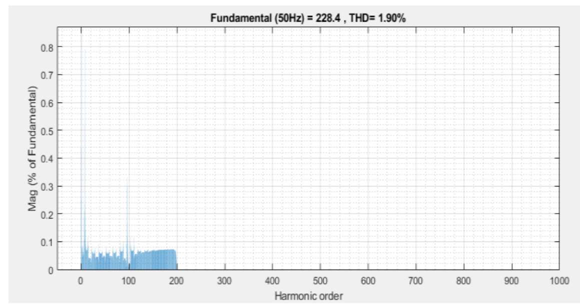

Fig. 21 THD% in FFT Voltage available at the load points in HV distribution system with renewable energy resources

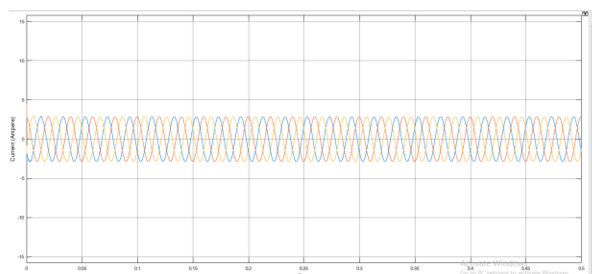

Fig. 22 Current drawn at the load points in HV distribution system with renewable energy resources

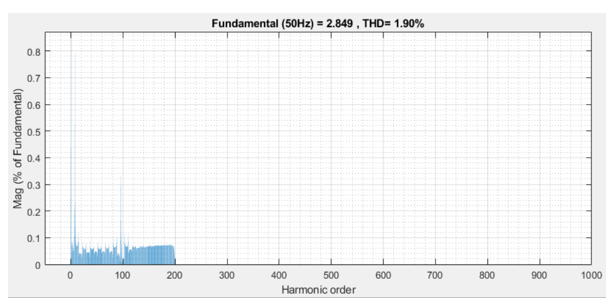

Fig. 23 THD% in the Current drawn at the load points in HV distribution system with renewable energy resources

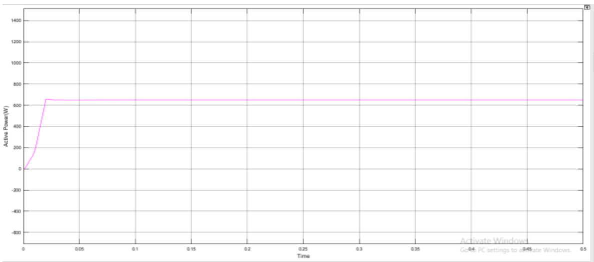

Fig. 24 Active power at the load points in HV distribution system with renewable energy resources

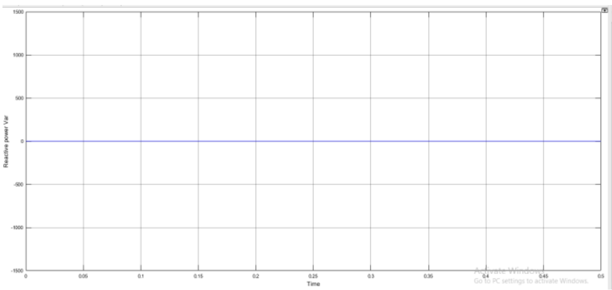

Fig. 25 Reactive Power at the load points in HV distribution system with renewable energy resources

The HV system analysis at the loading point having the solar/wind hybrid renewable energy system in the grid shows that the voltage of 228.4V has a distortion level of 1.90% and the current available at the load is approximately 2.85 A with the total harmonic distortion percentage of 1.90%. The system designed with various loads at low voltage distribution level shows that the active power available is 650.3W.

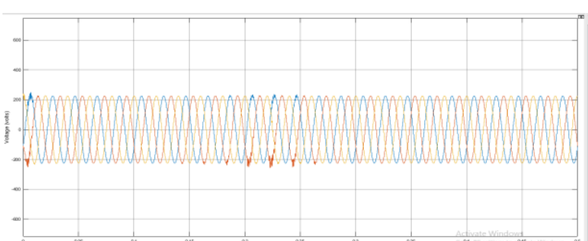

Fig. 26 Voltage available at the load points in LV distribution system with renewable energy resources

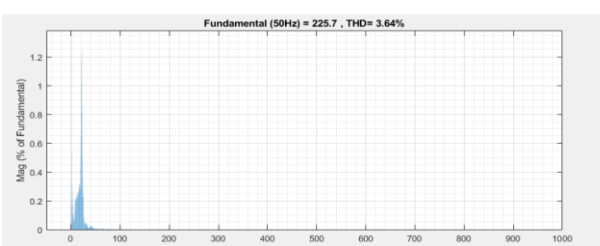

Fig. 27 THD% in Voltage available at the load points in LV distribution system with renewable energy resources

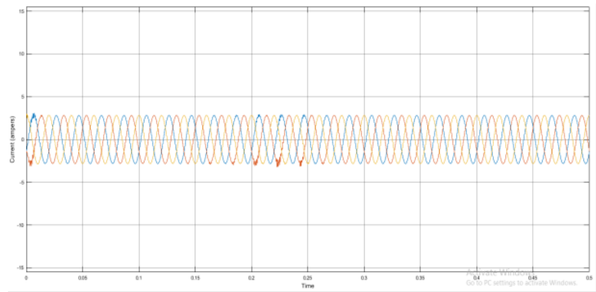

Fig. 28 Current drawn at the load points in LV distribution system with renewable energy resources

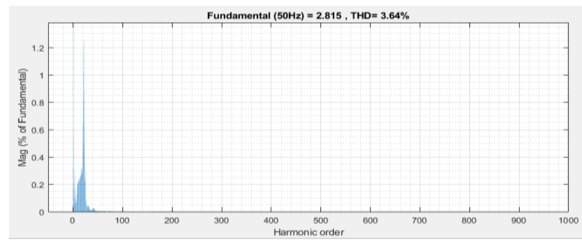

Fig. 29 THD% in Current drawn at the load points in LV distribution system with renewable energy resources

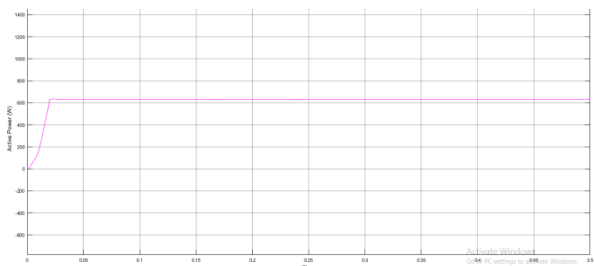

Fig. 30 Active Power at the load points in LV distribution system with renewable energy resources

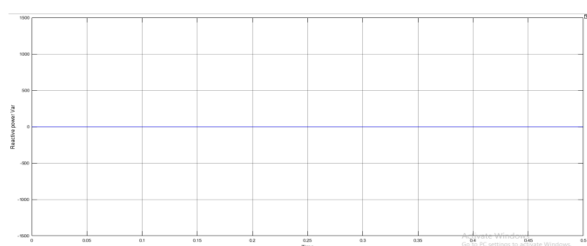

Fig. 31 Reactive Power at the load points in LV distribution system with renewable energy resources

The LV system analysis at the loading point having the solar/wind hybrid renewable energy system in the grid shows that the voltage of 225.7V has a distortion level of 3.64% and the current available at the load is approximately 2.81 A with the total harmonic distortion percentage of 3.64%. The system designed with various loads at low voltage distribution level shows that the active power available is 635W.

2 HV and LV system study with grid interfaced solar wind energy systems at the transmission line

The analysis has been extended to study the effects of loading reflected on the high voltage transmission line. The system is this case also comprises of the feeding from the renewable energy resource that is hybrid solar/wind energy systems.

The voltage waveforms are being analyzed in this case for determining their distortion level by calculating the Fourier transform of the voltage waveform. The study has been conducted in the transmission line bus before the bulk transformer in case of the LV distribution system. In case of the HV distribution system, the bus before the small transformers have been selected for the analysis.

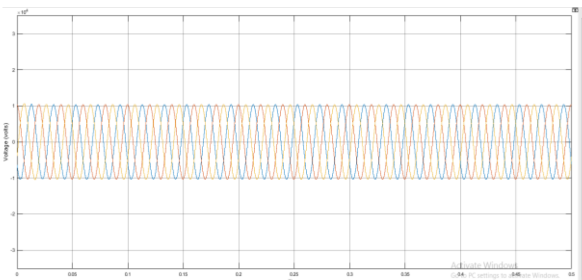

Fig. 32 Transmission line voltage in the 11KV line for HV distribution system with the renewable energy resources

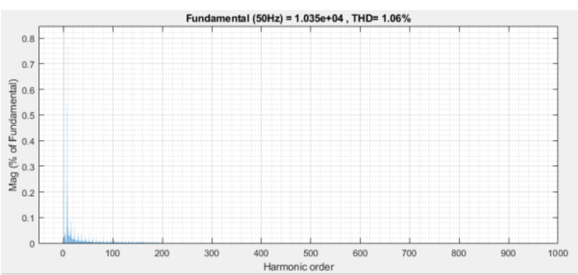

Fig. 33 THD% in Transmission line voltage in the 11KV line for HV distribution system with the renewable energy resources

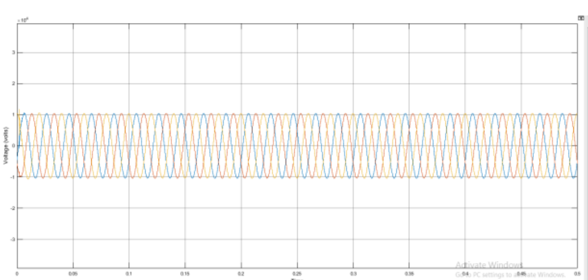

Fig. 34 Transmission line voltage in the 11KV line for LV distribution system with the renewable energy resources

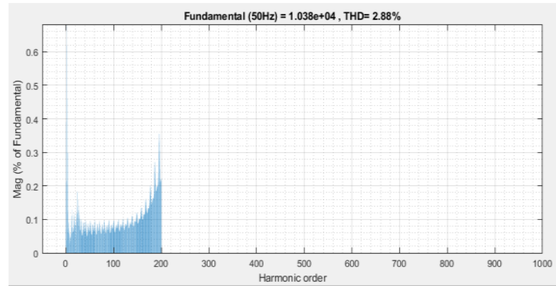

Fig. 35 THD% in transmission line voltage in the 11KV line for HV distribution system with the renewable energy resources

In this case as well, where systems comprised of another solar/wind resources the system analysis confirmed the effectiveness of high voltage distribution system than low voltage distribution system in respect of the THD% reflected on the high voltage line as well due to loading. The distortion in HV system was found to be less 1.06% than that of the LV system which as 2.88% in the voltage waveform.

3 Comparative analysis of low voltage distribution system with high voltage distribution system comprising of solar/wind hybrid energy systems.

The renewable energy resources are being subjected to the variable irradiation and wind parameters as a result of the environmental factors. Their integration with any distribution system can bring about certain stability issues and need to be monitored carefully. In this segment we have brought about the comparative analysis of the previously modeled HV distribution system with the LV distribution system by further integrating them with the solar/wind hybrid energy system.

The table brings about the percentage and value improvement in various electrical parameters of the distribution system and concludes further the efficiency of the HV distribution system in terms of the power restores as a result of reduced losses when compared with the LV distribution system.

$$\% \, increase \; in \; active \; power = \frac{new \; AP - old \; AP}{old \; AP} \; x \; 100$$

$$= \frac{650.3 - 635}{635} \text{ x } 100$$

= approx 2.4%

Table 2: Comparative analysis of electrical parameters from the HV and LV systems having renewable energy resources.

S no.	Parameters studied for the comparative study	Parameters at the low voltage distribution system	Parameters at the high voltage distribution system	Improvement detection

1	THD% of voltage at the load line	3.64 %	1.90%	Reduced by 1.74
2	Peak Value of voltage recovered	225.7 V	228.4 V	2.7 V recovered
3	THD% of current at the load line	3.64 %	1.90%	Reduced by 1.74
4	Magnitude of current available at the terminal	2.815 A	2.85 A	Reduced current loss
5	Active Power available (Watts)	635 W	650.3 W	2.4 % increase in power
6	Reactive Power	0 Var	0 Var	-
7	Effect of loading on 11KV line in terms of THD% in voltage	2.88%	1.06%	Reduced by 1.82

While transmitting power to the loads at certain distances using the transformer close to them (HV system) the waveform of voltage and current where found to be less distorted but in case of using the bulk transformer and then driving loads at certain point because of the distance increased between the transformer and load the waveform where more distorted and certain losses also occurred. The distortion was additionally increased due to some of the renewable energy loading factors. Table 5.2 concludes Reduction in line losses since HV line is taken almost up to consumer load point.

VI. CONCLUSION

The work is focused on bringing about the comparative analysis on the outcomes at the load points in the low voltage distribution system and the high voltage distribution system. The results have depicted a reduction in the losses at the load busses with improvement in voltage and current profile. The comparative conclusions depicted the following key recoveries:

- Improvement in voltage profile with distortion reduction from 0.07% to 0.05% at the loading terminal in HV distribution system analysis. The voltage recovered was approximately 3V. Similar enhancement was observed in case of current in the high voltage distribution system.
- The improvement in the current along with the voltage profile brought about an enhancement in the active power available as well by about 3%
- The effect of loading on the transmission line was less in HV distribution system than in LV distribution system

Based on the optimization process, the results of the comparative analysis revealed the following: the optimized HVDS has a better voltage profile which results in improved voltage profile; system losses reduction decreases the operational cost and increases the annual capitalized loss savings in the optimal HVDS. This study is therefore an innovative approach in selecting unit transformers needed in a migration from LVDS to HVDS that will provide reliable and economical services to service providers.

The study was further extended to develop the low voltage distribution system and high voltage distribution system for renewable energy resources integrated with 11KV line as well. The results concluded the following key observations:

- The power output was found to be enhance as a result of improvement in the voltage and current outcomes available at the load terminal effectively by 2.4%
- The voltage and current profile with the solar wind hybrid systems were studied to be less distorted having THD% of 1.90% than in the low voltage distribution system where the distortion level was 3.64%.
- As in the case above, the effect of loading on the high voltage 11KV was also less to be about 1.06% in HV distribution system than 2.88% in LV distribution system.

VII. FUTURE SCOPE

Following aspects are identified for further scope of research work.

1. The present work can be extended to power system with generalized TCSC, STATCOM and Interline Power Flow Controller (IPFC).
2. The system investigated has been limited up to a two renewable based power system. It would be desirable to extend the proposed approach for larger and more realistic systems.
3. The present work can be extended for STATCOM and SSSC with energy storage such as battery Energy Storage System (BESS) and Superconducting Magnetic Storage (SMSS) for enhancing power system stability.

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