Feasibility Analysis of Implementing DC Distribution for Industrial Areas

K. Murali Krishnan and A.N. Ravishankar

Abstract--- *The presence of power electronic equipment in the utility and customer side results in the extensive use of DC power in the system. A DC power system helps to reduce the unnecessary conversion stages thus helps in the reduction of losses in the system. This also helps to reduce in the transmission and distribution losses and also reduces the bulk use of conductors. So DC power system will become one of main power system network in the future.*

This paper analyzes a distribution system having industrial and residential loads that run in DC system. The power management algorithm helps in effective management of power between the consumers. The objective of the power management strategy is to achieve optimal operational performance providing high power quality, reliability and efficient energy dispatch. This helps in the effective allocation of power to the customers according to the priority, thus helping the stability of the system. For this, a distribution system consisting of industrial loads with and without captive/in-house generation facility along with residential consumers is considered. Simulation studies were carried out using MATLAB/Simulink platform. The proposed DC distribution system validated with a case study of implementing the same in an industrial area called KINFRA Industrial park at Thiruvananthapuram, Kerala, India.

Index Terms— *DC Distribution, Energy Management strategy, Distributed Generation*

I. INTRODUCTION

RECENT developments and trends in the electric power consumption clearly indicate an increasing use of DC power in end-user equipment. Computers, TVs, and other electronic-based apparatus use low-voltage DC obtained by means of a single-phase rectifier followed by a DC voltage regulator. In factories, the same input stage is used for process-control equipment, while directly-fed AC machines have been replaced by AC drives that include a two-stage conversion process. Electrical energy production from renewable sources is at DC (as in photovoltaic systems and fuel cells) or requires a similar two-stage conversion as in AC drives, e.g. variable-speed wind turbines and natural-gas micro-turbines. By using DC for distribution systems it would thus be possible to skip one stage in the conversion in all these cases, with consequent savings and higher reliability due to a decreased number of components. Moreover, energy delivery at DC is characterized by lower losses and voltage drops in lines.

A full DC power system helps in safer, more reliable, stable, flexible and controllable DC power grids that could serve the people better than that of the present AC power systems. The DC distribution finds application now due to the extensive presence of electronics components in the distribution system. The presence of online UPS in the residential areas and offices and use of power electronic drives in industries led to the extensive use of DC in the system. The distribution system receives power either from an AC transmission system or DC transmission system. If it is a DC system the DC-DC transformer step down to distribution level voltage and it fed to the customers according to their requirements. In an AC system, it is step down to secondary distribution voltage using step down transformer. From there DC distribution is made with the help of rectifier system, which is given to the consumers.

This paper describes a new design having DC distribution for industry loads. The presence of DC loads signifies the distribution in DC for industry loads. DC distribution also reduces the bulk use of conductors. The power system is having a considerable amount of it's generation and transmission sector using DC in the respective areas. The transmission sector have started using the HVDC transmission in the power sector, the generation sector is also witnessing the DC generation with the use of renewable resources in the system like the microgrid. The wind, solar powered generation has taken a part of the generation sector and it is growing rapidly. It is said that the solar PV has attained grid parity in some countries and wind will also attain it in the near future. The distribution sector is also witnessing a considerable amount of DC powered system due to the increased use of power electronic equipment in the loads. The industries are also using power electronic equipment for controlling its mAChines in there plants. Thus the entire three sectors are also witnessing a considerable presence of DC in the power system. Thus a DC power system can be visualized in the near future.

A DC distribution system also allows direct connection of battery blocks for backup energy storage. The latter is often needed for avoiding supply interruptions in hospitals or big office buildings or in industrial complexes with high power quality demands and is presently implemented with Uninterruptible Power Supply (UPS) systems using two conversions (from AC to DC and back). A direct connection to a DC network would thus save two conversions in this case.

K. Murali Krishnan, PG student (Power & Energy Engineering), Dept. of Electrical & Electronics Engineering, Amrita School of Engineering (Amritapuri Campus), Kollam, Kerala, India.

A.N. Ravishankar, Asst. Professor, Dept. of Electrical & Electronics, Amrita School of Engineering (Amritapuri Campus), Kollam, Kerala, India.

II. KINFRA INDUSTRIAL PARK

The KINFRA (Kerala Industrial Infrastructure Development Corporation) industrial park in Thiruvananthapuram consists of two division KINFRA international apparel park and KINFRA small industries park. The park is situated at 8.55805260 N and 76.8546867 E at Thiruvananthapuram District of Kerala, India. The park consists of more than 50 industries which are spread at an area of 90 acres of land. The main industries working here are garment industries, printing and publishing industries, medical oxygen manufactures which are the HT consumers and many small scale industries. The industries that are taken for study are HT consumers were there are a considerable amount of DC/Drive loads. The HT consumers have separate transformer in their premises and they step down the voltage to 400 V AC. The total connected load of the park is 5990 kVA out of which 3857 kVA is the load taken for studying. The electrical layout of the existing system is shown in Fig. 1. The connection to the park is taken from two 11kV feeders from the state electricity board. From the incoming bus the supply is distributed to different parts of the park and from the secondary bus bars (SS1-SS8) the industries took the supply.

The time of operation of industries differs depending on the type of products produced by them. The electrical loads of different industries and their time of operation is described in Table 1. The first column represents the industries. The industries that are selected include garment industries (2^{nd}, 4^{th}, 5^{th}, 6^{th}), medical oxygen manufactures (1^{st}, 8^{th}), newspaper publishers (3^{rd},7^{th}), plastic manufactures (10^{th}), medical equipment manufacturers (9^{th}), and the other industries are grouped into a single load (11^{th}). From the table we can see that the medical oxygen manufacturing unit works for whole day. The print and press industry work during mid-night and early morning and all other industry work from 9.00am to 5:00pm.

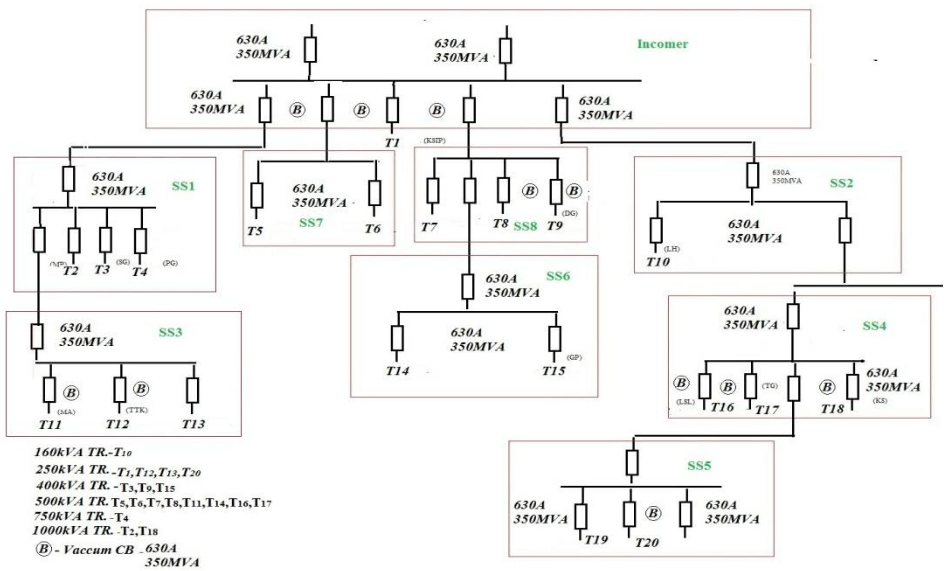

Fig. 1. Electrical Layout of the PARK

Table.1. Electrical load details of the park

I	Tr. Rating (kVA)	Loads (kVA)				Time of operation (h)	Diesel Generators ratings (kVA)
		Connected	Max	AC	DC		
1	250	200	120	158	42	0-24	200
2	250	200	120	190	10	9-17	200
3	1500	1250	600	568	682	20-4	1500
4	250	200	120	173	27	9-17	200
5	250	240	200	215	25	9-17	250
6	500	400	350	330	70	9-17	400
7	1000	900	500	440	460	20-4	900
8	250	167	100	131	36	0-24	200
9	160	100	60	76	24	9-17	-
10	250	200	120	145	55	9-17	200

The loads within the industries are separately calculated and are written as AC loads and DC loads. The machines using drives are also taken as DC loads. From the table it is seen that most of the industries are having considerable amount of AC loads except two industries which belong to printing and publishing category. The load profile of the industries for a particular day by considering it's connected load, maximum demand (MD), AC loads and DC loads and drives is shown in Fig. 2. The selected industries are only taken into Account while plotting the graph. The graph will provide an overview of the type of loads and their time of operation which helps to find the power requirement of the particular day. From the fig 2 it is clear that there is a clear difference between the connected load and the maximum demand of industries. Most of the HT consumers are having their own backup supply whenever there is a failure of supply since there are some processes which cannot be interrupted while it takes place. Some others HT and LT consumers didn't have a backup diesel generator. So they don't have power when there is a power failure. If there is a mutual agreement between the industries they can have a power transfer between them during supply failure.

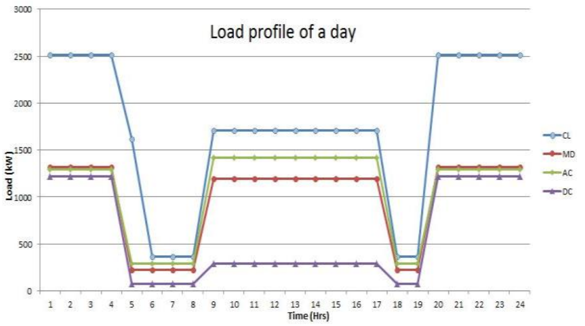

Fig. 2. Load Profile of the Selected Industries

III. PROPOSED DC DISTRIBUTION NETWORK

This section discusses in detail the designing of the industrial loads using DC distribution. It also discusses the changes that takes place in the system when AC distribution changes to DC. This system is modelled in MATLAB/Simulink software. A detailed analysis of eACh system is done in this chapter.

A. DC Distribution System

The DC distribution starts from the distribution level voltage ie, from 400 V. The distribution transformer step down the voltage to 400 V AC. This 400 V AC is rectified for the DC distribution system. The industries take the power from this DC bus for it's operation. The whole layout of the DC distribution system is shown in Fig. 3. Fig 4 represents the simulink block diagram of the designed distribution system in MATLAB/Simulink. A detailed describtion of the block are explained in the imminent part. For simulation industry 1 to 3 contains 2 industries together and industry 4 contains a group of three industries.

B. Utility Grid

The utility grid is modelled as an infinite bus connected to a step down transformer which gives a 400 V AC bus. The infinite source is taken as a 11kV 100 MVA three phase voltage source. The 400 V AC grid is obtained by a 25 MVA, 11k/400 V step down transformer.Fig. 5 shows the simulink diagram of the utility grid.

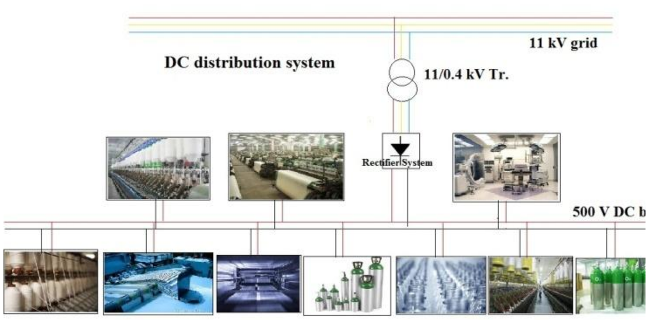

Fig.3. Block Diagram of the DC Distribution System

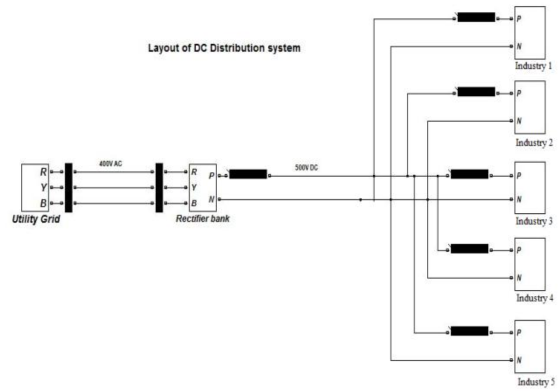

Fig.4. Simulink Diagram of the Distribution System

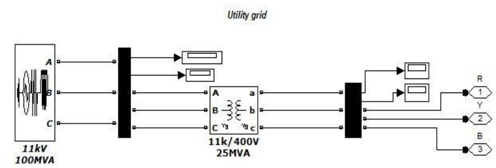

Fig 5 Simulink diagram of Utility grid

C. Electrical layout of Industry

The industry contains different loads depending upon the product it is making. All industries will be having AC and DC loads. Fig. 6 shows the designed Simulink diagram of industries in the industrial park.The DC loads contains machines working in DC as well as machines with drives. AC loads are connected with the help of a inverter circuit and the DC loads are directly connected to the grid. Some industries are having a diesel generator which is used as a backup supply. The diesel generator is also modelled within the industry subsystem. The diesel generator is directly connected to the system so that whenever the industry requires power the DG gives the power. This power is now not fed to the grid so that other industries can also be benefited. The AC loads contain three phase loads like induction motors and other electrical loads. The DC loads contains the AC machines controlled by drives and other DC powered equipments.

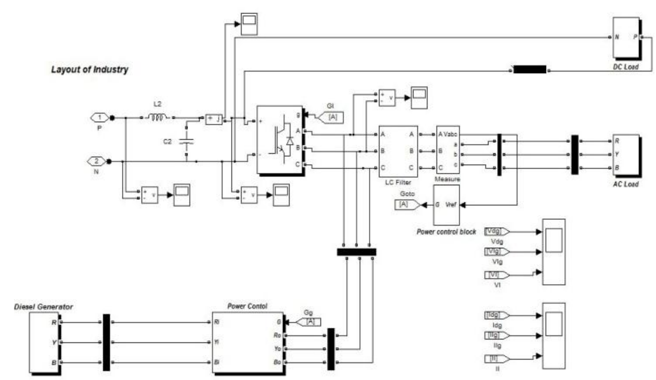

Fig. 6: Simulink Diagram of Industry

D. Diesel Generator

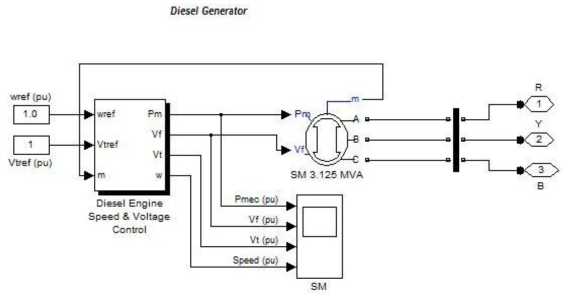

Fig. 7 Simulink Model of Diesel Generator

Diesel generator contains a deisel engine and a synchronous generator which is coupled together were the diesel engine drives the synchronous generator.The rating of this backup generator is as the ratind mentioned in table 1. The synchronous generator may have different rating for different industries. The Fig. 7 shows a simulink model of deisel generator connected to the system. The control of synchronous generator is done by the diesel engine speed and and voltage control block. This block diagram is modelled with the assistance from MATLAB demo. The rating of the diesel generator is mentioned in table1.

E. *Diesel Engine Speed and Voltage Control Block*

A synchronous generator contains a prime mover for rotating the rotar and also a field excitation for producing the magnetic flux.

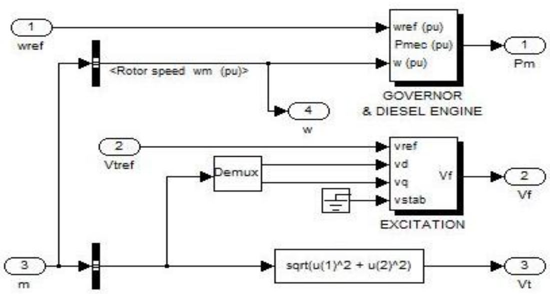

Fig 8 Simulink Model of the Diesel Engine Speed and Voltage Control

This two control are done in this block. The governor and diesel engine block helps in controlling the speed of the rotor and the excitation of the system helps to maintain the generating voltege constant. This diagram is in the diesel engine speed & voltage control.

IV. ENERGY/POWER MANAGEMENT STRATEGY

This section describes in detail the idea of effective utilization of energy within the industrial area. This can be used if there is more than one energy source supplying power. This help in reducing the cost by using much efficient resources. This method has its significance if there are renewable energy power source supplying to the grid or area were distributed generation happens. Due to increasing trend of electricity tariff based on usage, sometimes the utility tariff may be greater when compared to in house/ back up supply. So backup supply cost may be less than the utility supply tariff.

The industrial area as mentioned is having a utility connection from the state electricity board. Some industries are also having its own backup diesel generator which is used when there is a power failure.

Table 2. Time on Demand Tariff for HT & EHT Consumers

	Normal Period (6 to 18 hrs)	Peak period (10 to 22 hrs)	Off Peak (22 to 6 hrs)
Demand Energy Charges	100% 100%	150% 140%	80% 85%
ToD tariff for LT IV (Applicable for LT industries having C/L of 20 kW and above)			
Demand Energy Charges	100%	125%	80%

By using the energy/ power management system apart from selecting the diesel generator during power failure it is able to select either the utility power or diesel generator power depending upon the energy tariff. The tariff structure of HT-I (Industrial) is Rs 4.1/unit and a demand charge of Rs. 300/kVA/month. The tariff structure of LT-IV (Industrial) is about Rs. 4.25/unit and a fixed charge of Rs.60/kW. The industrial consumers are having ToD tariff structures were the tariff changes depending upon the traffic in demand. The time on demand (ToD) tariff for the consumers is given in table 2

Since the industrial park is having a large area which is unutilized. If that area is utilized for generating solar based power, there is a large opportunity for employing energy/power management system. Using the power management strategy the user is able to effectively decide which power to be consumed depending upon the electricity cost. The roof top solar PV can also be effectively done in this area. So that electricity cost can be reduced. If renewable energy resources are used it will be used according to its availability and rest will be met from the utility. If excess energy is there is can be stored in some storage devices and can be used during peak time when electricity cost is more. The existing system is having only having two energy sources the utility power and from the diesel generator, were the usual practice is to use the diesel generator only during non availability of utility power. So the power/energgy management staterrgy is having less importance.

V. SIMULATION RESULTS

The DC distribution system results for industrial loads with power management system with isolated energy source or with combined energy source are described in this section.

A. DC Distribution System with Isolated Energy Sources

In the simulation the whole system in simulated for 2 sec in which the system gets utility power from 0.1 to 1 sec and from 1 sec there is a power failure till 1.9 sec, so that the power is met with the diesel generator with in the industries.

Fig. 9 shows the utility grid voltage. There are able to supply it at the standard voltage level. Fig. 10 shows the voltage obtained at the load side of each industry. The above one shows the load side voltage of the DC bus in each industry. This also represent the DC grid voltage of the entire system. The middle one shows inverter output voltage and the bottom show the voltage at the AC bus within the industry. The load side AC voltage is obtained by filtering the inverter output voltage.

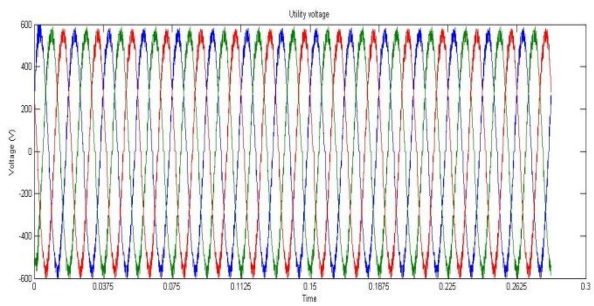

Fig.9. Utility Voltage

From the graph it is clear that the DC bus voltage and the AC voltage is maintaining a constant voltage of 540 V and 400 V AC respectively. Fig. 11 shows the power flow within the industry during power production from either from utility or from diesel generator. The figure also represent the power consumed the DC and AC loads of that particular industry. The grid requirement met by the two sources. the diagram shows the power flow at the output of the inverter. The power from 0.1 sec to 1 sec is from the utility and from 1 to 1.9 sec the diesel generator is supplying power. In the fig 11 the first one in top represent the utility power usuage by the industries, the second one represent the AC load consumption. The third one represent the power consumed from the diesel generator and the last figure represent the DC load consumption. The utility delivers about 450 kVA and the load consumes about 390 kVA and the diesel generator delivers about 400 kVA .

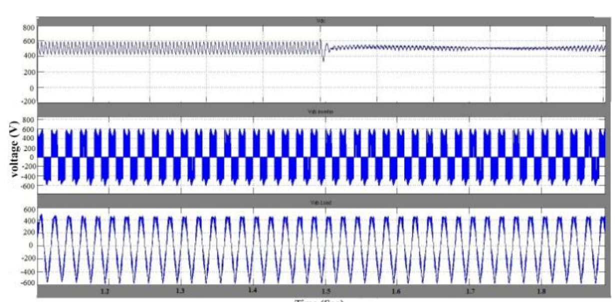

Fig.10: Voltage Waveform at the Load Side using Isolated Energy Sources

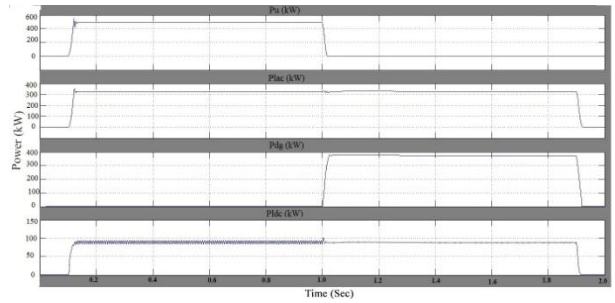

Fig. 11 Power flow during isolated power production

The entire industrial area is simulated for 4 sec with 0 to 2 sec the area works with diesel generator and the rest of the time it consumes power from the utility. In this the entire industris are grouped as 5 groups. The industries working at the same time is grouped as single industry and the industry without diesel generator is grouped as an industry. Fig. 12 represents the total power delivered by the utilities and total power consumed by the industries the above one represents the power consumed by the industries and the below represents the power given by the utilities. The load consumes about 3.75 MVA and the utility delivers amout 4 MVA.

For simulation industries are grouped into 5 groups out as in fig 4 of which four industries are having a backup diesel generator and the 5th industry is not having the backup power supply. The industry block in the simulink diagram may contain the rating of two or three industries, ie industry block 1 to 3 contains the rating of 2 industries each working at same time and the 4th industry block contain 3 industries rating. If there is a power transfer agrement between the industries they can trade off within themselves. The fig. 13 shows the power variation of different diesel generators while delevering power to the industrial area. Variations exists because the diesel generators as it distribute power to the industries not having backup supply.

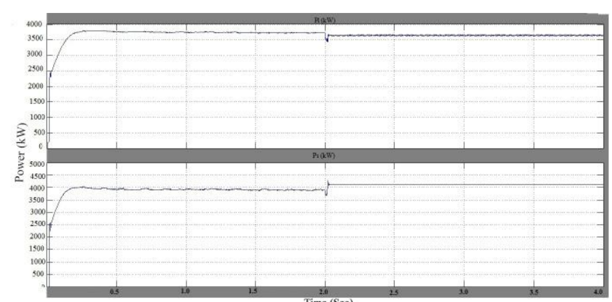

Fig. 12: Power Flow in the Utility and Demand Side

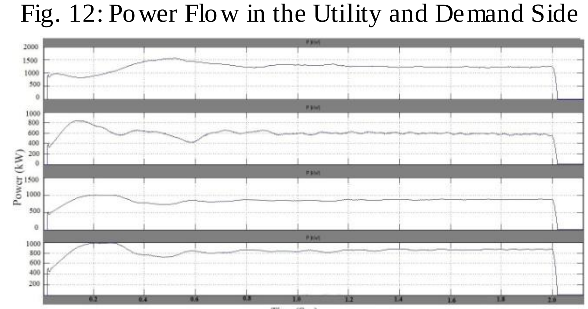

Fig. 13: Power Variation by Different Diesel Generator

B. Power Flow within the Industries Throughout the Day

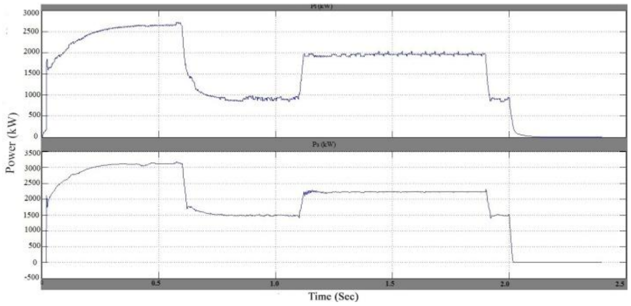

Fig.14: Power Flow in the Supply and Load Side

In this the entire industrial area is taken and simulated for a particular day. Each hour is taken as 0.1 sec and simulated for 2.4 sec. Each industry is kept on according to its working time in the real scenario. In this simulation the area is consuming power only from the grid. Fig.14 shows the power flow in the industrial area with the above figure showing the power consumption of the loads and the other figure showing the power drawn from the utility. Fig. 15 shows the voltage waveform at the load side of a particular industry. The top figure shows the DC link voltage, the middle one represents the output voltage of inverter and the lower figure shows the voltage after filter which is fed to the load. The results obtained are same as the results shown in Fig. 10. For the sake of doing simulation the starting time is taken as 10 pm when the printing and publishing industry start working. Also for doing the simulation faster two or more industries load details are combined together and simulated. The time of operation of all industries are mentioned above. The utility is able to provide the power effectively to the industries even if the distribution system is DC.

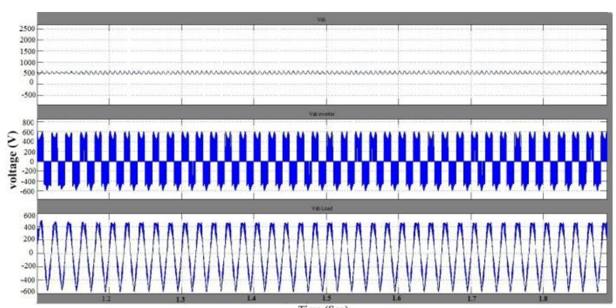

Fig.15: Voltage Waveform at the Load Side of a Particular Industry

VI. CONCLUSION

This paper is considering a feasibility analysis of industrial area powered by a DC system. In this electrical data's of the industries are collected and while designing the DC system these data's are included in the system. A Power management strategy is also included in the system so that power can be effectively transferred within the industrial area with and without power faliure occurring within the plant. The simulation results show that the DC distribution system is feasible for an industrial area. Power management strategy within the industrial area helps in the effective power transfer.

REFERENCES

[1]. Reza Noroozian, Mehrdad Abedi,Gevorg Gharehpetian, "Combined operation of AC and DC distribution system with distributed generation units", *Journal of electrical engineering*, VOL. 61, NO. 4, 2010, pp 193–204.

[2]. Mesut E. Baran, and Nikhil R. Mahajan, "DC Distribution for Industrial Systems: Opportunities and Challenges", *IEEE transactions on industry applications*, vol. 39, no. 6, November/December 2003.

[3]. Qianzhi Zhou and Defang Yuan, "Prediction on Future DC Power System," *IEEE 6th International Power Electronics and Motion Control Conference, 2009*, IPEMC '09. Page 1192 – 1195, 17-20 May 2009.

[4]. Gab-Su Seo, Jongbok Baek, Kyusik Choi, Hyunsu Bae, Bohyung Cho, "Modeling and Analysis of DC Distribution Systems", *8th International Conference on Power Electronics - ECCE Asia*, May 30-June 3, 2011, Shilla Jeju, Korea.

[5]. Gilsung Byeon, Taeyoung Yoon, Seaseung Oh, and Gilsoo Jang, "Energy Management Strategy of the DC Distribution System in Buildings Using the EV Service Model", *IEEE transactions on power electronics*, vol. 28, no. 4, April 2013.

[6]. Ambra Sannino, Giovanna Postiglione, and Math H. J. Bollen, "Feasibility of a DC Network for Commercial FACilities", *IEEE transactions on industry applications*, vol. 39, no. 5, September/ October 2003.

[7]. Tero Kaipia, Pasi Salonen, Jukka Lassila, Jarmo Partanen, "Possibilities of the low voltage DC distribution systems", *Scientific Bulletin of the Petru Maior University of Tirgu Mures*, Vol. 6 (XXIII), 2009, ISSN 1841-926.

[8]. Daniel Nilsson, and Ambra Sannino, "Efficiency analysis of low- and medium voltage DC distribution systems", *IEEE Power Engineering Society General Meeting*, 2004, 10 June 2004, PP: 2315 - 2321, Vol.2.

[9]. PANG, Huey, LO, Edward W.C. and PONG, Bryan M.H. "A prACtical and efficient DC distribution system for commercial and residential applications - 240V or higher?", *International Conference on Electrical Engineering (ICEE'08),* Hong Kong, 19-21 March, 2008.

Ravishankar A N, Received his B.Tech and M.Tech from National institute of Technology, Calicut. Currently he is working as an Asst. professor at Amrita School of Engineering, Amritapuri campus, Kollam, Kerala, India

Murali Krishnan, Received his B.Tech Degree from AWH Engineering College, Kozhikode. Currently he is pursuing M. Tech Degree in Power and Energy Engineering at Amrita School of Engineering, Amritapuri campus, Kollam, Kerala, India