

Incorporation of LVDC concept in IEEE Recommended Practice System for Interconnecting DERs in Secondary Distribution System

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Abstract— Electrical power, in the short span of two centuries, has become an indispensable part of modern day life. Even a temporary stoppage of power can lead to relative chaos, monetary setbacks, and possible loss of life. Power outages can be especially disastrous when it comes to life-support systems in places like hospitals and nursing homes, or in co-ordination facilities such as in airports, train stations, and traffic control. Power outages occur due to many causes like natural disturbances, internal power surges, manmade disturbances, and line faults and many more. Among all, the power outages due to natural causes will remain from weeks to months. Distributed Energy Resources (DERs) will be a best solution for this situation to obtain alternate power in post disaster conditions [1]. To interconnect DERs in the distribution systems IEEE has recommended a practice system, which is given by IEEE Std. 1547.6-2011. DERs can be Renewable Energy Sources (RES), Diesel Generators and storage devices (batteries or fuel cells) etc., depending on the availability. On the other hand, as most of the DERs provide power in the form of Direct Current (DC), Low Voltage DC (LVDC) power for distribution system is getting popularity. In this paper, IEEE recommended distribution system for interconnecting DERs is designed. A standalone PV system is designed as a DER. The IEEE recommended practice system is modified to incorporate LVDC distribution system to obtain power from DERs.

Index Terms— DERs, RES, Solar Photo Voltaic (PV), LVDC, Intentional Islanding .

1 INTRODUCTION

Rural area electrification in developing countries like India helps to improve the quality of life of the people and education. It also demoralizes people from moving towards urban areas. In India, nearly 70% of the population is living in rural areas. To achieve better living standards and developments in these areas, it is necessary to electrify the villages. Since these areas are located far away from the power generating stations, transmission and distribution of power to these areas is a difficult task, which does not allow achieving 100% electrification in the country. In electrified rural areas, a heavy load shedding has been carried out for longer time as the load demand is increasing day by day. In these situations alternate power can be obtained from DERs, which form locally confined micro grids at distribution level. The day-to-day activities that rely on electricity are from the basics, like cooking the family meal, water heaters, cooling system, communication systems and heating our homes, to key infrastructure services like petrol pumps, and modern conveniences like automatic doors and many more.

Most of the electrical loads like lights, automatic doors, communication devices, power backup devices and DERs or RES basically work on DC power.

Many researchers developed LVDC distribution systems to improve the reliability and efficiency of the distribution systems including DERs [2], [3]. The IEEE recommended practice system for interconnecting DERs in secondary electrical distribution systems, show the interconnection of DERs in conventional AC distribution system. To improve its reliability, an attempt is made in this paper to incorporate LVDC distribution system in the IEEE recommended practice system.

2 IEEE RECOMMENDED DISTRIBUTION SYSTEM FOR INTERCONNECTING DERs

In 1920 to provide highly reliable electric service to concentrated load centres, secondary distribution networks were first developed. These were primarily used in the downtown areas of major cities. They are classified as spot networks and grid networks (also referred to as *area networks* and *street networks*). An area Electric Power System (EPS) may have multiple grid networks operated independently from one another within a city. Customers take service from the network at the secondary network voltage level, with no interposing transformer. Grid networks serve many customers over a dispersed area. A spot network serves one or a limited number of customers at one location. In either case, network service increases reliability compared to other forms of service. Traditionally, area EPS secondary networks were not designed to accommodate generation. Many concerns are associated with the application of DER on secondary networks. The operating strategy for integration of DER into a spot network requires positive power flow from the network into the facility. DER interconnection

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should not cause inadvertent operation of the network parameters. To address these IEEE has provided recommendations and guidelines for interconnecting DERs on the distribution secondary networks, including both spot and grid networks. The standards of the system are given as IEEE Std 1547.6-2011 [4]. The block diagram of IEEE recommended practice system is shown in figure 1.

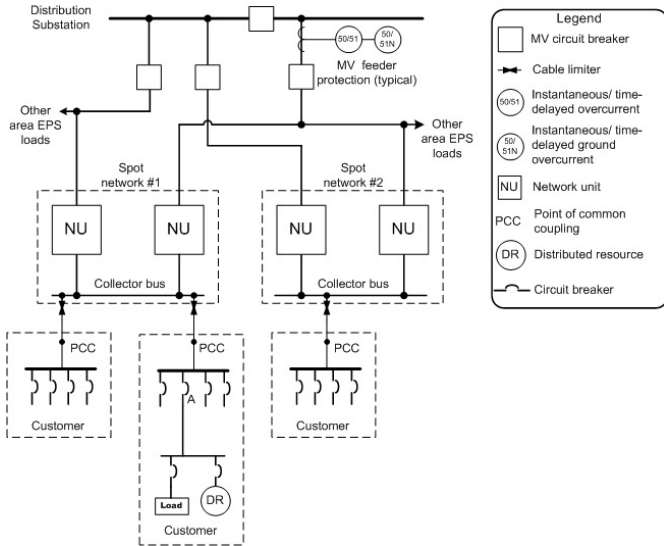


Figure 1. (IEEE Std 1547.6-2011) IEEE Recommended Practice for Interconnecting Distributed Resources with Electric Power Systems Distribution Secondary Networks [4].

This system is designed using MATLAB/Simulink for implementation of proposed algorithm.

3 LOW VOLTAGE DC (LVDC) DISTRIBUTION SYSTEM

LVDC distribution system on comparison with conventional AC system has following advantages:

- Higher efficiency
- Reliability
- Fewer conversion stages
- Uninterrupted power delivery

Furthermore, RES such as photovoltaic power generation, wind power generation, and electric vehicles are considered to be good alternatives in electric power systems. These distributed resources and electric vehicles generate and use DC voltage, so they must interface with DC distribution systems, which are more efficient than the existing AC distribution systems when dealing with DC-based sources and devices. Due to these advantages, it is expected that the installation of DC systems in housing complexes, buildings, etc. will increase. For this reason, the demand for applications of DC systems has increased. The development of the Low-Voltage DC (LVDC) network was started in 2005 in Finland as a continuum to the development of 1kV intermediate LVDC distribution systems. It is shown by many researchers that the losses in converters due to the conversion stage can be significantly reduced by applying an LVDC system, the total system losses will be decreased compared to those of the conventional AC network.

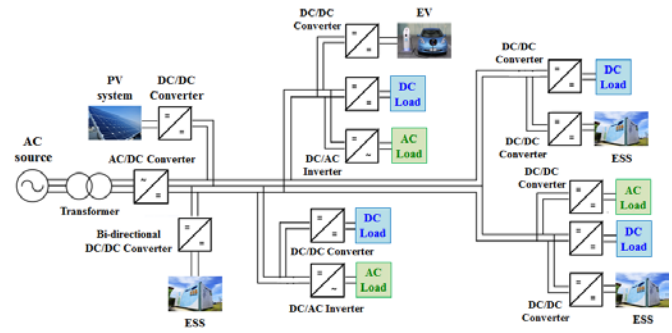


Figure 2. Concept of an LVDC Distribution System.

A practical implementation of DC residential loads connected to Standalone PV System is carried out. A comparative analysis for both technical and economical performances of DC loads with AC residential loads is obtained. Published results and the literature conclude that the implementation of an LVDC distribution system is more beneficial than an AC system [5], [6].

Figure 2 shows the concept of an LVDC distribution system. Unlike a conventional AC system, an LVDC system needs power electronic devices. In addition, the DER and various types of load are connected to the main DC system through the power electronic devices.

4 MODIFIED IEEE RECOMMENDED SECONDARY DISTRIBUTION SYSTEM

It is observed that the IEEE recommended practice system works with AC supply and the loads connected are also AC. In order to implement the concept of LVDC distribution system, power electronic devices are added at required locations in IEEE recommended practice system. The loads are also modified to work with DC power. The modified IEEE recommended system is shown in figure 3.

It is observed from figure 3 that, the modifications made to the IEEE system are shown in red colored circle. The modified system is designed with three DC feeders with three loads on each feeder i.e., nine DC loads are connected through individual breakers. Power electronic device which is considered here is a Rectifier (represented as R) to convert AC power to DC power. If the power is unavailable from DER, then the AC power drawn from main grid is rectified and supplies the DC loads. If the power is taken from DERs or Batteries, then it is readily available in DC.

It is assumed here that, for half of the duration of execution time the main grid is supplying power to the loads and in rest half time, the grid is turned OFF and the power to loads is obtained from DER. This execution is carried out for the systems, one with conventional AC distribution system and another with LVDC distribution.

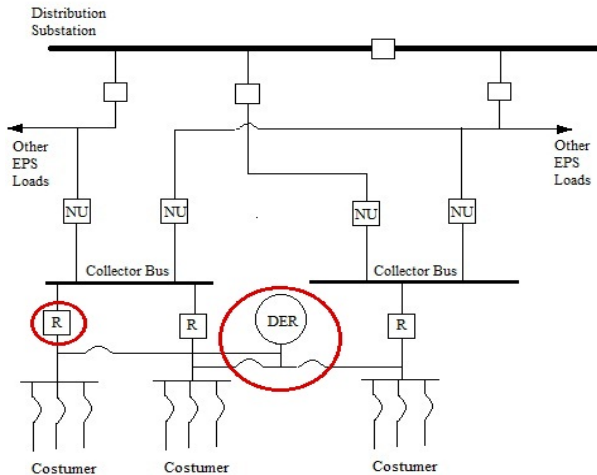


Figure 3. Modified IEEE Recommended Practice for Interconnecting Distributed Resources with Electric Power Systems Distribution Secondary Network incorporating LVDC Distribution.

5 DESIGN OF STANDALONE PV SYSTEM

Due to its inexhaustible and environmental friendly nature, standalone PV system is considered as DER in this work. Solar array is made of series and parallel connections of solar cells in large scale. Designing of such complicated array in MATLAB/Simulink becomes a challenge. To avoid these complications, solar array can be implemented in MATLAB with the help of equivalent circuit. Equivalent circuit of PV cell is given in figure 4.

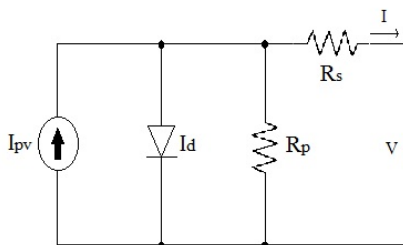


Figure 4. Equivalent Circuit of PV Cell.

The basic equation that describes the characteristics of an ideal PV cell [7] is given by equation 1.

$$I = I_o[\exp((V+IR_s)/V_t)-1]-(V+IR_s)/R_p \quad (1)$$

Where

$$V_t = N_s kT/q$$

V_t is the thermal voltage across the panel with N_s number cells connected in series. Series connected cells provides increased

output voltage and parallel connected cells increase currents. The current generated in normal conditions by the array, given by equation 2, is calculated based on the temperature and radiation falling on the panel. The current I_d is the current flowing through the diode connected across the current source in PV cell equivalent circuit; this current is given by equation 3. The diode saturation current I_o is given by equation 4.

$$I_{PV} = (I_{pv,n} k \Delta T) G / G_n \quad (2)$$

$$I_d = I_o [\exp(qV/kT) - 1] \quad (3)$$

$$I_o = (I_{sc} + k_i \Delta T) / \exp[(V_{oc} + k_i \Delta T) / V_t] - 1 \quad (4)$$

Where $I_{pv,n}$, is the light generated current at nominal condition (usually at 25°C and 1000 W/m^2), $\Delta T = T - T_n$ (actual and nominal temperatures) G and G_n (actual and nominal irradiances) falling on the surface of the array [W/m^2]. $I_{pv,n}$ is calculated from equation 5.

$$I_{pv,n} = ((R_p + R_s) / R_p) I_{sc,n} \quad (5)$$

To obtain the accurate characteristics of solar cell, series resistance R_s must be of small value and parallel resistance R_p should be of greater value. I-V curve of the PV cell is shown in figure 5.

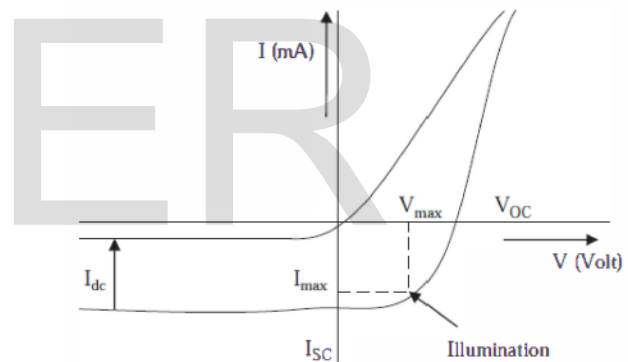


Figure 5. I-V curve of PV cell.

This model consists of a current source and a parallel diode which is simple, accurate and flexible to simulate with power converters.

6 SIMULATION AND RESULTS

6.1 System Design

The modified IEEE recommended practice system including LVDC distribution system shown in figure 3 is designed in MATLAB/ Simulink. This is shown in figure 7.

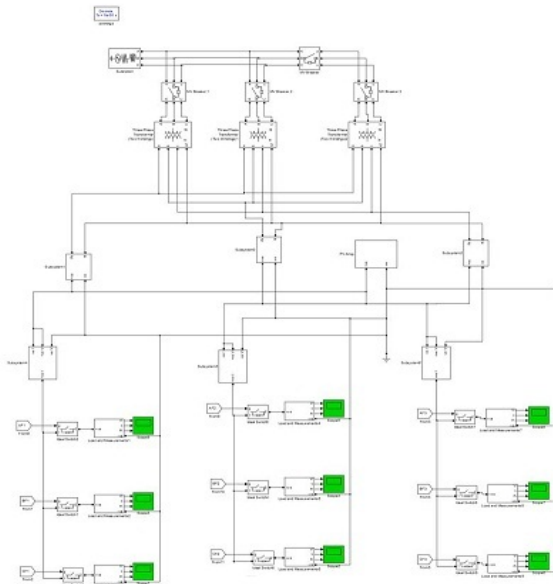


Figure 6. Simulink Model of Modified IEEE Recommended Practice for Interconnecting Distributed Resources with Electric Power Systems Distribution Secondary Network incorporating LVDC Distribution.

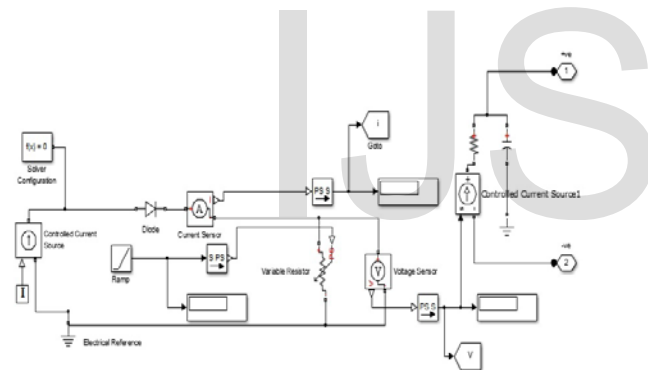


Figure 7. Simulink Model of PV Equivalent Circuit.

It is observed from figure 6 that, secondary substation is powering three medium voltage feeders of 11 kV through breakers. The power is further distributed to loads after stepping down to a voltage of 230 V L-N (440 V L-L). A single phase line is considered as a radial distributor, supplying power to residential loads. Three loads are connected on each distributor through respective switches. Power to the loads is obtained as per the assumption i.e., for first half the power is obtained from main grid and in the next half the power is obtained from DER.

6.2 Standalone PV System as DER

Mathematical model of PV cell and its various parameters are designed in MATLAB/Simulink using the equivalent circuit. The considered solar panel model for this work is ND-1240Q2 [7]. Specifications of this panel are given in table 1.

TABLE I. SPECIFICATIONS OF PV PANEL

Parameters of PV Panel	Rated Value
Open Circuit Voltage V_{oc}	37.5 V
Short Circuit Current I_{sc}	8.61 A
Maximum Output Power	240 W
Voltage at Maximum Power	30.2 V
Current at Maximum Power	7.95 A

The power generated by the PV, modelled as an equivalent current source is controlled by controlling the no. of series cells i.e., N_s and no. of parallel cells i.e., N_p variables. The characteristic equations that describe the array are designed using suitable math operations from the simulink library.

The simulink model is shown in Figure 7. This simulation is done for the standard test condition i.e. temperature is 25°C and Irradiation is 1000 W/m².

6.3 Results

Main grid is turned OFF due to many reasons like fault occurrence in the system, network disturbance due any disaster, load shedding and many more. In this situation, power to the loads is obtained from the available DER in the secondary distribution system. Power supplied to the loads of conventional AC distribution system and LVDC distribution system from main grid and DER are obtained. The power supplied to the three AC distributors D1, D2 and D3 before modifying to LVDC distribution system are shown in figures 8, 9 and 10 respectively.

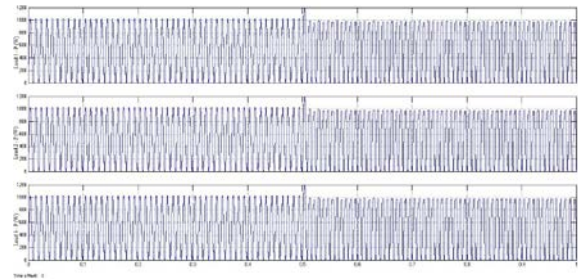


Figure 8. Power consumed by the three loads of distributor 1(D1) of IEEE practice system before modification.

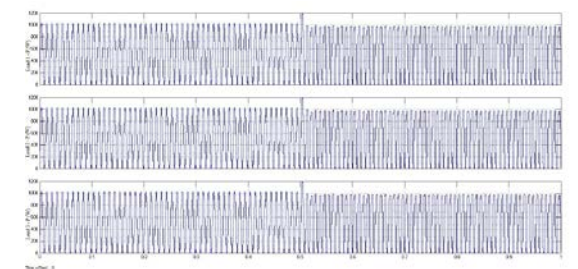


Figure 9. Power consumed by the three loads of distributor 2(D2) of IEEE practice system before modification.

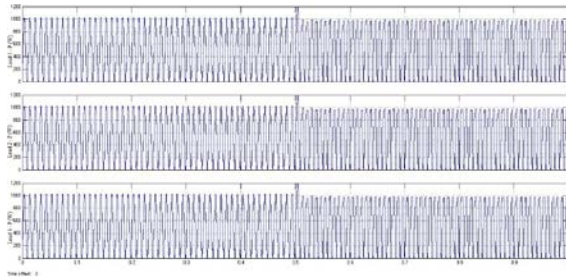


Figure 10. Power consumed by the three loads of distributor 3 (D3) of IEEE practice system before modification.

It is observed from figures 8, 9 and 10 that, power to the loads of three distributors is AC. For the first half of execution period i.e., up to time duration of 0.5 s, the power is obtained from main grid. In the next half time duration i.e., from 0.5 s to 1 s, the inverted power is obtained from DER. It is observed that, there is no difference in power supplied by the both main grid and DER i.e., 1000 W. As per the limitations the parameters like voltage and current applied for a single load are shown. These parameters will be similar for the remaining loads of the system. These are shown in figure 11.

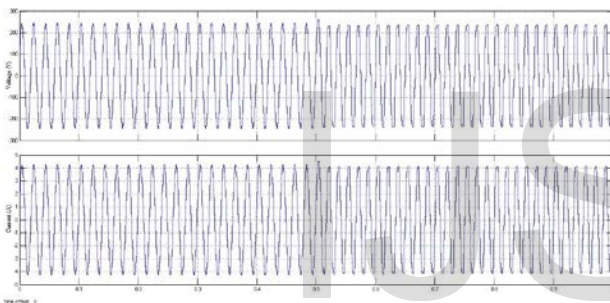


Figure 11. Parameters of Load 1 of Distributor 1 before modification: Voltage (V) and Current (A).

It is observed from figure 11 that, the voltage applied across the load is 230 V AC and the current supplied is 4 A. The power supplied to the loads after modification to LVDC distribution system for individual distributors D1, D2 and D3 are shown in figures 12, 13 and 14 respectively.

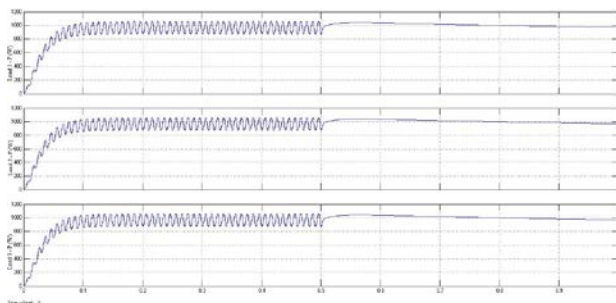


Figure 12. Power consumed by the three loads of distributor 1 (D1) of IEEE practice system after modification.

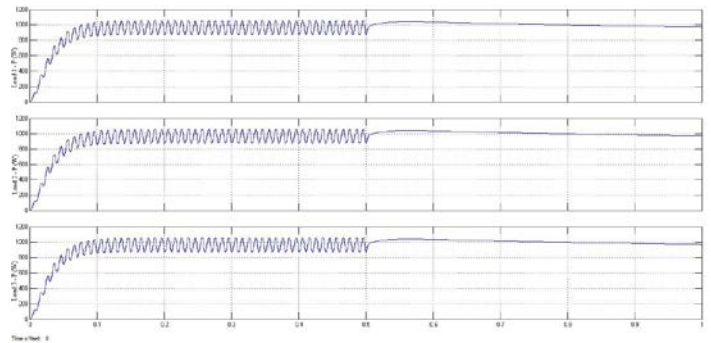


Figure 13. Power consumed by the three loads of distributor 2 (D2) of IEEE practice system after modification.

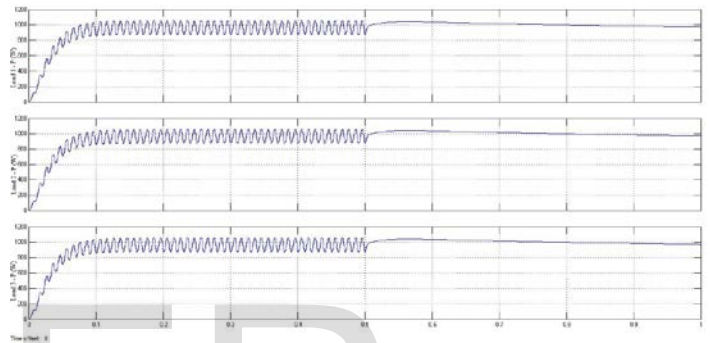


Figure 14. Power consumed by the three loads of distributor 3 (D3) of IEEE practice system after modification.

It is observed from figures 12, 13 and 14 that, power to the loads of three distributors is DC. For the first half of execution period i.e., upto time duration of 0.5 s, the rectified power is obtained from main grid. In the next half time duration i.e., from 0.5 s to 1 s, the DC power is obtained from DER. It is observed that, there is no difference in power supplied by both main grid and DER i.e., 1000 W. As per the limitations the parameters like voltage and current applied for a single load are shown. These parameters will be similar for the remaining loads of the system. These are shown in figure 15.

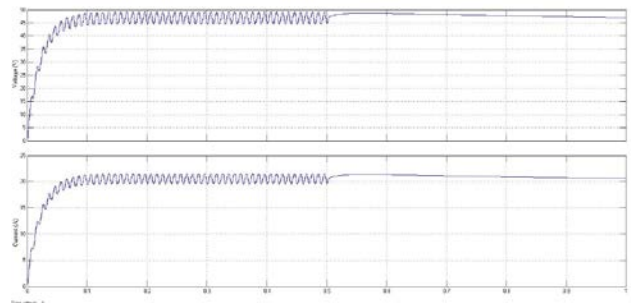


Figure 15. Parameters of Load 1 of Distributor 1 after modification: Voltage (V) and Current (A).

It is observed from figure 11 that, the voltage applied

across the load is 48 V DC and the current supplied is 22 A DC.

It is observed from the obtained results that the IEEE recommended practice system is modified to operate with LVDC distribution system without disturbing the actual operation of the system.

7 CONCLUSION

This paper presents the incorporation of LVDC distribution system in IEEE recommended practice system for interconnecting DERs in secondary distribution system. IEEE recommended practice system with convention AC distribution system and with LVDC distribution system incorporated are designed and simulated using MATLAB/Simulink. The obtained results show that, the modified IEEE system operates the same way with conventional AC distribution system. Results prove that, the IEEE recommended practice system can be used for further research in two ways, one with conventional AC distribution system and another with LVDC distribution system.

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