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Overcurrent Protection Scheme for Photovoltaic Based DC Microgrid

Kamble Pallavi Piraji, PG Student electrical Engineering Department, TSSM's BSCOER, Narhe, pune

Prof. A.P. Kinge, HOD of electrical department, TSSM's BSCOER, Narhe, pune

Prof. S. G.Shete, Assistant professor, Electrical Department, TSSM's BSCOER, narhe, pune

ABSTRACT

For protection of the LVDC distribution systems, the overcurrent-based protection is the first choice and the differential protection is the last choice. The differential protection needs the synchronizing and comparing functions. Implementing these functions for the LVDC system with high fault transients is difficult and expensive. Also, the differential protection does not provide the backup protection. On the other hand, it does not have complexities of the over-current protection like coordination and setting issues. This paper proposes an over-current protection scheme that is based on the use of the over-current relays for the protection of a radial LVDC system with PV units. The protection system must respond toboth utility grid and microgrid faults which isolates the smallest possible section of the radial feeder to eliminate the fault.

1. INTRODUCTION

IN DC microgrid, when fault occurs, the transient process of the fault current will have three stages. Viz; capacitance discharge stage where the fault current is mainly due to the discharge current of DC link capacitance, Full wave uncontrollable rectify stage when the DC link voltage goes less than AC phase voltage. This forward bias the freewheeling diode and causes alternate diodes to conduct, Three phase short circuit stage when the DC link voltage becomes zero which causes all the diodes to conduct at the same time DC link capacitor, in this stage, neither charge nor discharge. The design of the protection system mainly focused on fault detection fault isolation and fault location method.

The fault detection methods includes overcurrent protection protection, current derivative protection, directional overcurrent protection, distance protection and differential protection.

The fault isolation method includes the the protective devices like mechanical circuit breaker, solid state circuit breaker, hybrid circuit breaker and z-source circuit breaker, Fault location methods include travelling wave based fault location, differential fault location, injection based fault location and local measurement based fault location.

2 Modeling of PV system

Fig.1 .shows a PV array which is connected to the LVDC system through a DC/DC boost converter. Modeling of the PV arrays and control algorithms of the converter depend on the duration of the study. For long-term studies, especially in the field of the operation and control of the AC/DC micro-grids, a detailed model of the PV arrays is proposed, which considers the ambient temperature and solar radiation. In the grid- connected mode, a maximum power point tracking (MPPT) algorithm is utilized in the converter to deliver the maximum available power to the grid. In islanded mode, the converter works in voltagemode control to support the balance of power and regulate the DC voltage

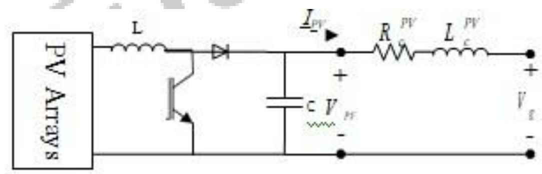

Fig. 1. A boost DC/DC converter connected to the PV arrays

The PV arrays are modeled as a constant DC voltage source interfaced with the grid through a power-electronic converter. Fast control algorithms are implemented to the converter to regulate current and voltage in grid-connected and islanded modes of operation so that the PV system acts like a constant power source.

3 Evaluation of using over-current protection

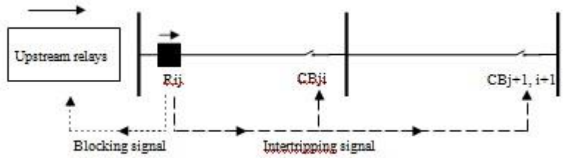

Fig.2 . Required communication paths for implementing the blocking and inter-tripping schemes

This paper proposes a comprehensive strategy as shown in Fig. 2 for selecting a proper protection scheme for the DC micro-grid protection. The strategy evaluates the possibility of using the over-current protection for every line section of the system. If a section can be protected using the proposed over-current scheme, the strategy determines which relays should to be set for the grid-connected and islanded operation modes of the micro-grid. It is assumed that a relay at one end of the section can send a trip command to the circuit breakers at both sides of it. Thus, if all the faults inside the section can be detected by one of the relays, the relay at the other side of the section does not require to be set. Therefore, the proposed strategy presents an economical approach to protect the system with minimum number of the relays

4 protective relay setting

Two protection zones are defined for each relay; the primary and the backup zones as shown in Fig. 1. The primary zone of the relay Rij covers the line Lij plus a portion of the subsequentline in the forward direction. Therefore, there is an overlapped area between primary zones of the relays. In fact, the overlapping is applied to guarantee the operation of the relayfor whole the line section. The backup zone of the relay Rij covers the line Li+1,j+1which is the primary zone of the relayRi+1,j+1. For example, R12should be the backup protection ofR23. In case of R23does not trip instantaneously, R12should tripafter a delay time which is defined as the discrimination margin The relay sends a trip command to the respective circuit breaker when it senses a current greater than If min ij flowing in the forward direction

For setting the over-current relays, four parameters are considered. Two time setting parameters (tset1ij, tset2ij) and two current setting parameters (Iset1ij, Iset2ij). The time parameters are chosen according to the DC fault current characteristic and the required time to clear the DC faults. The Fault currents in the LVDC systems have high transients and large amplitudes that can damage sensitive devices such as converters in both source and load sides

4.1 Protection and Communication logic

As shown in fig. 1 There is an overlapped area between the primary zones of the relays to guarantee their operation for whole the line sections. Also, because of the time limitation, the setting parameter tset1ijis chosen same for all the relays. Therefore, the relays coordination is necessary to prevent their simultaneous operation which causes the selectivity problems. In this paper, a blocking scheme is proposed to solve the coordination problems of the over-current relays as shown in fig 1

The setting parameter tset1ij is chosen same for the first-stage elements of all the relays. Therefore, the relays at both ends of a line can cover all faults occurring inside the section for all configurations of the PVs. In cases where the relay Rij cannot be set or fails to operate, the relay Rji can send a trip command to the circuit breakers at both sides of the line Lij to isolate the faulty section. This scheme is defined as the "inter-tripping" in which operation of a relay in one end causes a tripping signal to be transmitted to a circuit breaker at the other end of the zone. Note that, since the inter-tripping scheme is applied in the system protection, every line section can be protected by are lay which covers all the faults inside the section for all cases and the opposite side relay has not to be set. It can be set as a local backup function in case the inter-tripping scheme fails to operate. This enhances the dependability of the protection scheme.

The inter-tripping and blocking schemes can be implemented by considering communication paths shown in Fig. 2. The required time to transfer the blocking and inter-tripping signals between the IEDs and CBs is important for appropriate setting of the relays.

The relays should be set with a time delay that is greater than the communication delay to keep selectivity. The total communication delay consists of four components: transmission delay, queuing delay, propagation delay, and processing delay. Transmission and queuing delays are insignificant for advanced communication systems such as fiber-optic with high bandwidth. The delay is around 0.1mswith bandwidth 100-1000 Mb/s. The propagation delay is small for the LVDC systems with short lines (for 15miles the delays are 8.2µs-41µs). The processing delay can be minimised using advanced routing. For example, the delay is 0.35msfor64bytesPacketsizewith1.5Mb/slink, and it can be<5µs with 100Mb/s link size. Therefore, the total communication delay will be small enough to enable the blocking and inter-tripping signals to be transferred between the relays within timescale <1ms

4.2 Modeling of PV system

Fig. 3 .shows a PV array which is connected to the LVDC system through a DC/DC boost converter. Modeling of the PV arrays and control algorithms of the converter depend on the duration of the study. For long-term studies, especially in the field of the operation and control of the AC/DC micro-grids, a detailed model of the PV arrays is proposed, which considers the ambient temperature and solar radiation. In the grid- connected mode, a maximum power point tracking (MPPT) algorithm is utilized in the converter to deliver the maximum available power to the grid. In islanded mode, the converter works in voltagemode control to support the balance of power and regulate the DC voltage

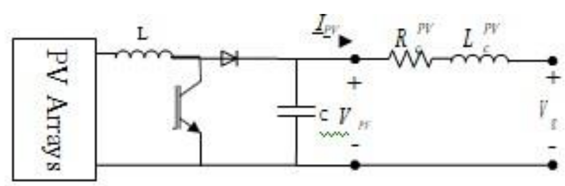

Fig.3. A boost DC/DC converter connected to the PV arrays

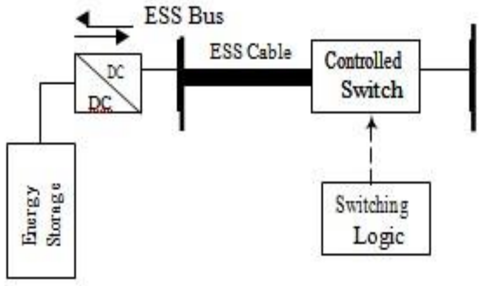

Fig. 4. Overall diagram of the energy storage system

Overall diagram of the energy storage system is shown in Fig.2 The energy storage is assumed as a constant DC voltage source which is connected to the ESS output bus through a bi- directional DC/DC converter. A control system similar to the voltage-mode control of the PV converter regulates the output voltage of the ESS. The ESS can operate in both charging and discharging modes regarding the grid operating conditions

5. CASESTUDY

5.1 Case Study Discription

The proposed protection method is tested on the low voltage DC distribution system shown in Fig. 1. The system has radial structure and is connected to the AC network through a controlled rectifier, which is grounded through a 0.1 ohm resistor. The output of the rectifier is connected to the main DC bus B1 through a circuit breaker which its state determines the operating mode of the microgrid. The DC micro-grid is divided to three line sections with four buses. The total line load is 68 KW. The load 1, added to bus 1, represents the total power of an identical feeder supplied from the main DC bus. Two PV- type DG units are assumed, which can be connected to buses1-The current-control mode is applied to both PV units in the grid-connected micro-grid operation, while in the islanded micro-grid one of the units operates in voltage-mode control.

6. PROPOSED SIMULATION MODEL

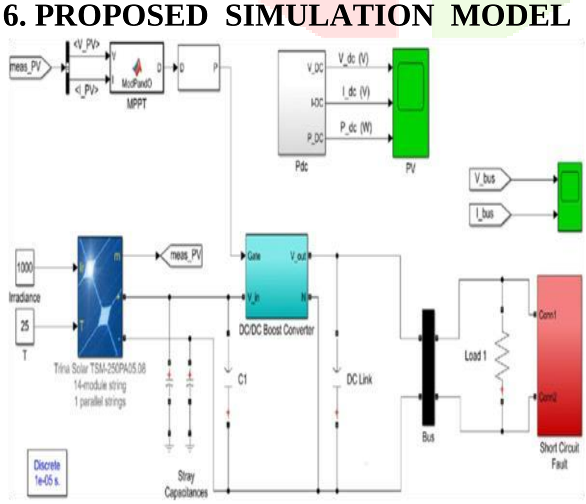

Fig 5. Proposed simulation model for overcurrent protection scheme.

6.1 SIMULATION RESULT

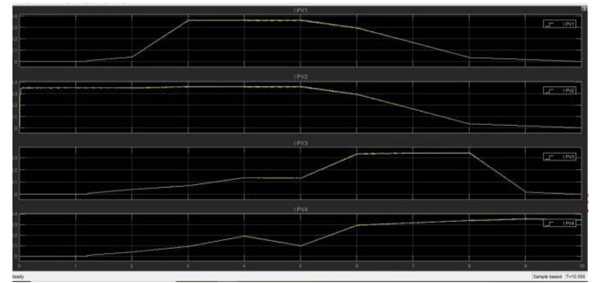

Fig. 6 observed waveform of proposed scheme

6.2 HARDWARE MODEL

Fig.7. Hardware model of proposed scheme

The system is simulated in the MATLAB software environment. Possible configurations of the PVs are considered and the fault analysis described is conducted to calculate the minimum fault current within the primary zone of every relay.

Table I summarize the maximum operation currents and the fault currents sensed by the relays for every configuration of the PVs in both islanded and grid- connected operation modes of the network. The PVs configurations are shown by Bi, Bi & Bj, and Bi (2 units). The symbol Bi means that a PV is integrated in the bus Bi. The symbol Bi & Bj means that one of the PVs is connected to the bus Bi and another is integrated in the bus Bj.Bi(2units)means that two PV units are connected to the bus Bi.

6.3 Comparision of proposed scheme with the scheme based on local measurement

The proposed protection scheme requires high-speed communication between the relays to guarantee the selectivity and the relays coordination. Recently for the fault detection in the DC micro-grid which are based on local measurements. They use first and second order derivatives for the faults detection. Since they are based on local measurements, the problems associated with the communication channel such as delay and dependability are avoided. However, the relays coordination, backup protection, and grounding issues are not discussed in these schemes. Also, first order and second order derivatives of the signal are very sensitive to noise level and switching of power electronic devices which may lead to unwanted tripping.

Meanwhile, a detailed analysis is presented to demonstrate the necessity of the communication for the local measurement based schemes as follows:

The local measurement based schemes presented in are applied on the multi-terminal DC micro-grids which have a ring configuration. In this configuration, all the faults occurred inside a cable are sensed by respective relays connected on both sides of the cable. However if a radial configuration is considered for the DC micro-grid, some faults are sensed only by a relay at one end of the cable and the relay at other end doesn't sense the fault Thus, each relay should have possibility of sending the trip command to the circuit breakers located at both sides of the cable to isolate the faulty section. Therefore, the inter-tripping scheme and the related communication paths are required. Also, the method presented in is applied on the test system of this paper to show the blocking scheme importance for the relays coordination. The fault current is sampled and its first order derivative is calculated. The sampling frequency is chosen as 10 KHz and the second sample is utilized for tripping decision. To simplify the analysis, it is assumed that the DC micro-grid is operated in grid-connected mode and only a PV can be integrated in buses 1-3. Minimum of the fault current derivative within the primary zone of every relay should be calculated

7. CONCLUSION

Over-current based protection is commonly applied for distribution systems with radial structure. In LVDC systems, the fault current has fast transients which make the coordination of the over-current relays a challenging issue. By utilizing the communication infrastructures of the modern smart grids, the blocking scheme is presented to overcome the coordination problems. On the other hand, integration of the PV units in the grid affects the amplitude and the direction of the fault currents. Thus, the directional over-current relays are used at both ends of the lines and their settings are upgraded for islanded and grid- connected modes of the micro-grid. By implementing the intertripping scheme, each one of the relays at one end of a line section can send a trip command to the circuit breakers at both ends of the section. Thus, a line section can be protected using the over-current relays if at least one of the relays at both ends of the section detects all the possible faults occurring inside the section for every configuration of the PVs. This is investigated using a new proposed evaluation strategy. If a section can be protected using the proposed over-current protection, the strategy determines minimum number of the relays which have to be set. Otherwise, the differential based protection is suggested for the section.

Therefore, possibility of using the cost-effective overcurrent protection is firstly analyzed by the proposed strategy and the differential protection is considered as the last option for the protection of a section. A sample DC micro-grid is modeled in detail and the proposed method is validated.

8. REFERENCES

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