DESIGN AND SIMULATION OF DIRECTIONAL OVERCURRENT RELAY COORDINATION SCHEME FOR GRID SYNCHRONIZED PV SYSTEM

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Abstract: Overcurrent relays are widely used for protection of power systems. Directional overcurrent relay respond to excessive current flow in a particular direction in the power system. The directional over current relay can protect a generator from voltage, reverse power, over current, loss-of-field, and over-excitation disturbances, while also providing breaker failure protection. If a directional over current relay is out of service, the consequences can be more severe since many protective functions may be incorporated into the unit. So, a second Backup relay could provide voltage, over current, directional power, and directional over-current protection as a backup. So for design of a system we need simulations software. Here we are using ETAP software. As ETAP is electrical power system analysis & operation software. ETAP offers and integrated and interactive software solutions for modeling, design, analysis, simulation, operation, control, optimization, and automation of electrical power system.

***Index Terms* - Grid connected photovoltaic system, PV array, Directional relay, Protection**

I. INTRODUCTION

Every day, the sun delivers energy to the earth free of charge. we can use this free energy thanks to a technology called photovoltaic, which converts the sun's energy into electricity. The conversion of light into electrical energy using photovoltaic effect can be achieved by conversion of naturally available solar energy into electrical energy. Electromotive force is generated by the absorption of ionizing radiation is defined as photovoltaic effect. Solar cell are the energy conversion devices which convert the solar energy to electrical energy based on photovoltaic effect.

A. Design of Grid Connected PV System

A grid connected photovoltaic power system is an electrical generating solar PV power system that connected to the utility grid. A grid connected PV system consists of solar panels, one or several inverters, a power conditioning units and grid connections equipment. A grid-connected PV system feeds to the grid. But when sun is unavailable or solar insolation is insufficient to generate power, it draws power from grid. Grid interconnection raises various issues out of which significant ones are interconnection voltage level, feeder reliability, protection and power quality issues. Protective relaying is concerned with the redundancy and reliability of the system.

Load flow, voltage stability and short circuit analysis are always required for proper installation, stable & reliable operation, and protective scheme of a power plant. Load flow analysis is a mathematical approach and tool used by electrical engineers for planning and determining various buses voltages, their phase angles, real and reactive power passing from all system components under normal steady operation. The most commonly used iterative methods in solving power flow problems are the Newton- Raphson, the Gauss Seidel, and the Fast Decoupled method. NR method is more reliable because it converges faster and it takes least number of iterations when compared with the other methods.

So for design of a system we need simulations software. Here we are using ETAP software. The proposed protection scheme equipped with directional overcurrent relays is tested using ETAP software. As ETAP is electrical power system analysis & operation software. ETAP offers and integrated and interactive software solutions for modelling, design, analysis, simulation, operation, control, optimization, and automation of electrical power system.

B. Protection of Grid Connected PV System

Directional overcurrent relay respond to excessive current flow in a particular direction in the power system. This directional over current relay employs the principle of actuation of the relay, when the fault current flows into the relay in a particular direction.

If the power flow is in the opposite direction, the relay will not operate. The directional over current relay can protect a generator from voltage, reverse power, over current, loss-of-field, and over-excitation disturbances, while also providing breaker failure protection. If a directional over current relay is out of service, the consequences can be more severe since many protective functions may be incorporated into the unit. So, a second Backup relay could provide voltage, over current, directional power, and directional over-current protection as a backup.

II. DETAILS OF THE ELECTRICAL NETWORK

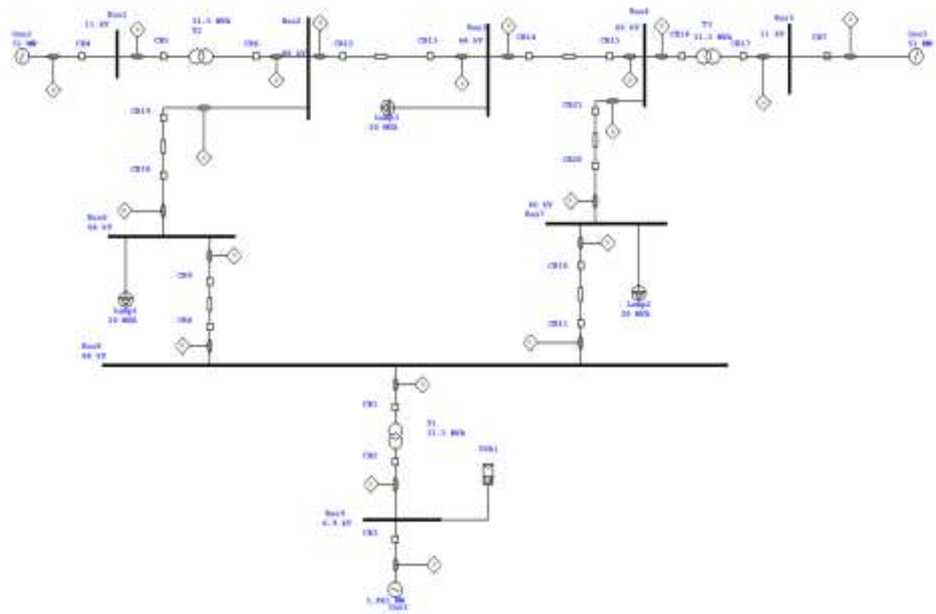

Figure 1Electrical Network

For design of grid connected PV system there are the various components required such as generators, renewable sources, transmission line, load and buses. Also for the protection devices also require. So, for design the model the given necessary components and that value also need to be determine.

III. LOAD FLOW AND SHORT CIRCUIT ANALYSIS

A. Load flow Analysis

In a three phase ac power system active and reactive power flows from the generating station to the load through different networks buses and branches. The flow of active and reactive power is called power flow or load flow. Power flow studies provide a systematic mathematical approach for determination of various bus voltages, there phase angle active and reactive power flows through different branches, generators and loads under steady state condition. Power flow analysis is used to determine the steady state operating condition of a power system. Power flow analysis is widely used by power distribution professional during the planning and operation of power distribution system.

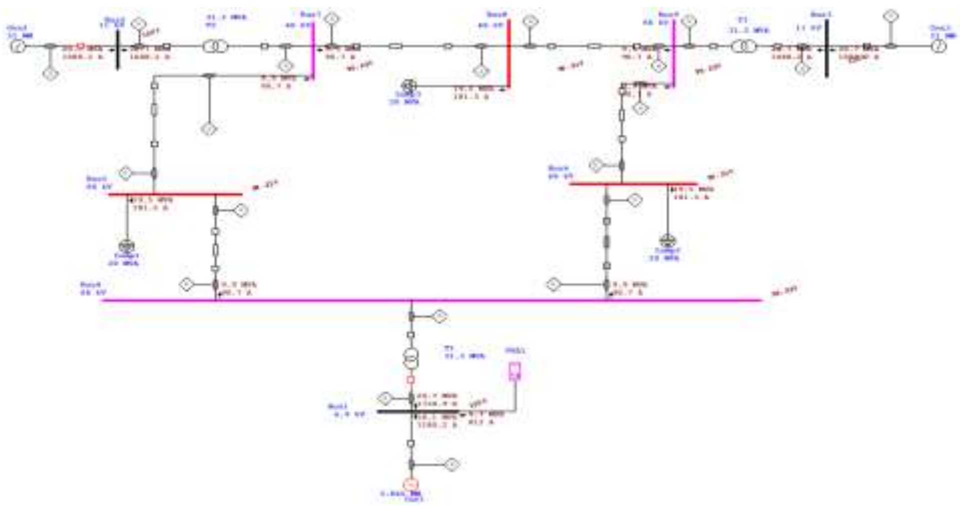

Figure 2load flow

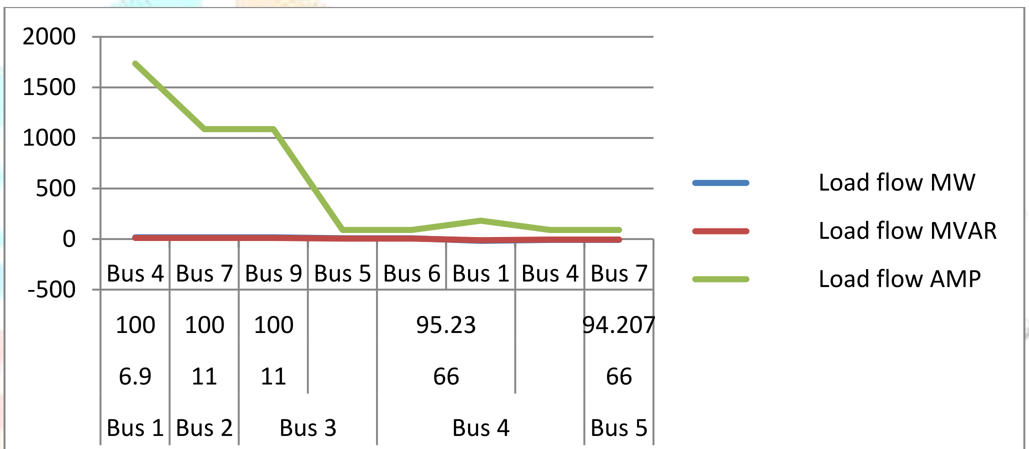

Figure 3Load Flow results of 1 to 5 Buses

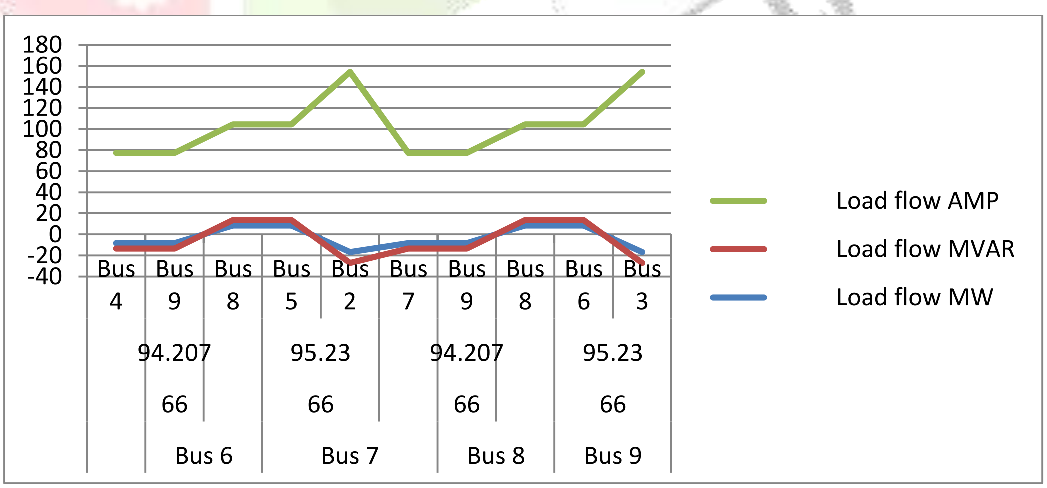

Figure 4Load Flow results of 6 to 9 Buses

Here we are using Newton-Raphson method for load flow analysis. From that we are using rated voltage and the rated current for the protection scheme design.

B. Short Circuit Analysis

The short circuit fault is occurring mostly due to failure of insulation. As the short circuit there are the faults current in the phases in network. In this paper fault is occur at bus no 5 which is the PCC of the network. In which the short circuit analysis is gives the information about the fault current of the phases and the voltage parameter of the network.

	3-Phase	L-G	L-L	L-L-G
Initial Symmetrical Current (kA, rms)	4.118	2.864	3.582	3.782
Peak Current (kA)	9.440	6.566	8.211	8.671
Breaking Current (kA, rms, symm)		2.864	3.582	3.782
Steady State Current (kA, rms)	1.704	2.864	3.582	3.782

Table 1Short Circuit Analysis

IV. PROTECTION SCHEME DESIGN

Here for the protection of the network we built a protection scheme design. Here two type of protection scheme design
1) Circuit Breaker Sizing
2) C.T Sizing

1. Circuit Breaker Sizing

We are using HIGH VOLTAGE CIRCUIT BREAKER. Circuit breaker is a mechanical switching device capable of making, carrying and breaking current under normal circuit condition as well as under specified abnormal circuit condition such as short circuit etc.

Circuit breaker sizing is decided according to IS:13118 (specification for high voltage alternating current circuit breaker).

1) **Rated Frequency:** 50 cycles
2) **Rated normal current:** According to IS:13118 standard value of normal currents are 400A; 630A; 800A; 1250A; 1600A; 2000A; 2500A; 3500A; 4000A; 5000A; 6300A etc.
3) **Rated Short Circuit Breaking Current:**. The standard values breaking current being 6.3 kA, 8 kA, 10 kA,12.5 kA kA,16 kA, 20kA, 25 kA, 31.5kA, 40 kA, 50 kA, 63 kA, 80 kA, 100 kA.
4) **Rated Short Circuit Making Current:** As per IS: 13118 rated short circuit making current should be at least 2.5 times the rms value of the A. C. component of its rated short circuit breaking current.
5) **First Pole to Clear Factors:** The ratio of transient voltage that appears across the contacts at the instant of arc extinction to service frequency recovery voltage is called the restriking voltage first pole to clear factor. The ratio of FPC factor is 1.3or 1.5.
6) **Rated Transient Recovery Voltage (TRV) for terminal faults:** The rated transient recovery voltage (TRV) for terminal faults relating to the rated short-circuit breaking current is the reference voltage. This constitutes the limit of the prospective transient recovery voltage of circuits, which the circuit breaker will be capable of breaking in the event of a short circuit at its terminals. TRV of 6.9KV, 11KV, 66KV is 12.3,20.6, 124TRV.
7) **Rated voltage:** In case of generator circuit breakers the rated maximum voltage should be equal to the maximum operating voltage of the generator which is usually equal to 1.05 times rated voltage.

Nominal system voltage KV rms 11KV,33KV, 66KV,132KV,220KV is rated voltage of C.B kV rms is 12,36,72.5,145,245.

2. C.T Sizing

The current transformer is used for the measurement of the current passing through it. In which the CT is measuring the alternating current. In which CT have the two winding inside the primary winding and secondary winding are there. The primary winding is connected in the series with the measuring lines. The CT used in the protection is the protection class CT.

Where the CT having the primary and secondary rating is based on IS: 13118. In which the primary rating is from the rated current flow in the CT. which is taken from the load flow analysis. Secondary rating is 1 A or 5 A for measurement. Here we are using 1 A for secondary of the CT.

C.T class: 5p20

C.T burden: 2.5 VA

C.T primary rating: According to Indian standard 50 A, 75 A,100 A, 150 A, 200 A, 300 A, 400 A, 600 A, 800 A, 1200 A, 1500 A, 2000 A, 30200 A, 4000 A.

Secondary rating of C.T: 5 amp.

V. LINKNET STRUCTURE

The first task of relay coordination process is to store the network information optimally in the computer memory. LINKNET structure is used to store the topology power system network. The topological operations of power networks are required in coordination studies to identify the relay pairs corresponding to each possible location of faults and for storing as well as retrieving the various data, whenever required in the relay coordination algorithm. In this structure, the bus numbers are assigned manually, but the computer assigns relays numbers (branch-end numbers) sequentially. In others words, in coordination studies, the relays are assigned numbers by LINKNET commensurate with the bus numbers, which are assigned by the user. A procedure to constitute the LINKENT structure vectors for any power network is described in the flowchart shown in fig.5 The topological properties are represented by specifying the connections between the nodes and the branches assuming that the ends of each branch are numbered as follows:

End_A = f (branch) = (2*branch) - 1

End_B = f (branch) = (2*branch)

Three one-dimensional vectors that are used in the LINKNET structure are described here.

Bus links: List (node) or list (bus) is a vector that stores all the bus links. It has the dimension of the number of buses in the system. For any given bus, the element list (bus) points to the first branch end on the list from bus.

Directional relay links: To store the links between the directional relays incident at given bus, next vector is used. For any given relay incident at a bus, the element next (end) or next (relay) points to the next branch end on the list after end. The last relay incident at the bus is indicated when the element next (relay) assumes a zero value. The dimension of the vector next is equal to the number of branch ends, that is, the relays in the system.

Remote relay links: far (end) vector is used to links any relay with its remote bus. It points to the node at the far or opposite end of the branch.

LINKENET Flowchart that is used to constitute the LINKENET structure by simply adding each branch to the network

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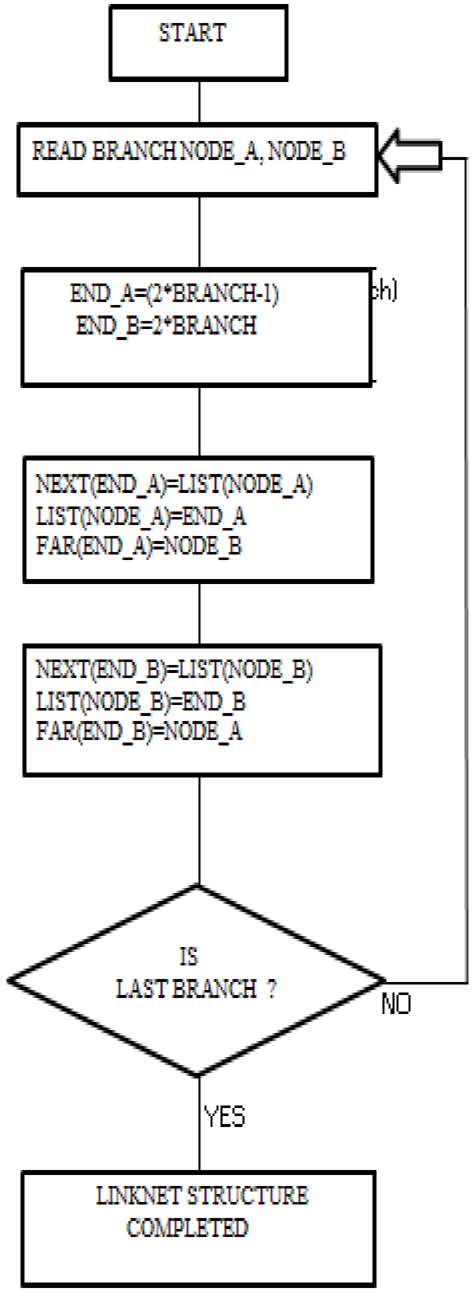

Figure 5LINKENET Flowchart

- **LINKENT structure table:**

1) **No. of Buses = 9**
2) **No. of Branch = 9**

Branch	Node	End	Next(N)	List(L)	Far(F)
1	Node_A=1	End_A=1	N(1)=L(1)=0	L(1)=1	F(1)=2
	Node_B=2	End_B=2	N(2)=L(2)=0	L(2)=2	F(2)=1
2	Node_A=2	End_A=3	N(3)=L(2)=2	L(2)=3	F(3)=3
	Node_B=3	End_B=4	N(4)=L(3)=0	L(3)=4	F(4)=2
3	Node_A=2	End_A=5	N(5)=L(2)=3	L(2)=5	F(5)=6
	Node_B=6	End_B=6	N(6)=L(6)=0	L(6)=6	F(6)=2
4	Node_A=3	End_A=7	N(7)=L(3)=4	L(3)=7	F(7)=4
	Node_B=4	End_B=8	N(8)=L(4)=0	L(4)=8	F(8)=3
5	Node_A=4	End_A=9	N(9)=L(4)=8	L(4)=9	F(9)=5
	Node_B=5	End_B=10	N(10)=L(5)=0	L(5)=10	F(10)=4
6	Node_A=4	End_A=11	N(11)=L(4)=9	L(4)=11	F(11)=7
	Node_B=7	End_B=12	N(12)=L(7)=0	L(7)=12	F(12)=4
7	Node_A=7	End_A=13	N(13)=L(7)=12	L(7)=13	F(13)=8
	Node_B=8	End_B=14	N(14)=L(8)=0	L(8)=14	F(14)=7
8	Node_A=6	End_A=15	N(15)=L(6)=6	L(6)=15	F(15)=8
	Node_B=8	End_B=16	N(16)=L(8)=14	L(8)=16	F(16)=6
9	Node_A=8	End_A=17	N(17)=L(8)=16	L(8)=17	F(17)=9
	Node_A=9	End_B=18	N(18)=L(9)=0	L(9)=18	F(18)=8

Table 2LINKENT structure table

VI. PRIMARY BACKUP RELAY PAIRS

Once the LINKNET structure is established, the next step is to determine the primary/backup relay pairs. Before finding the primary/backup relay pairs, load flow studies and short-circuit studies are essential.

The flowchart for the determination of primary/backup relay pairs is shown in flowchart. It is applied network such as radial feeder, parallel feeder, and ring networks. The steps of the algorithm are explained here.

1) Initially, the relay is considered as odd or even.
2) Afterwards, IFLT (the bus number near which the relay under considered is located), IB (first directional relay looking towards this bus),and IS (bus on which opposite end relay is placed) are obtained.
3) Subsequently, IF (bus near which the backup relay to the relay under consideration is placed) and IN (the next directional relay incident at bus IFLT) are calculated.
4) After two/three decision logic blocks, primary/backup relay pairs are found out.
5) Once the primary/backup relay pairs are obtained, the next step is to determine the PS(pickup current) and TDSs of all the relays.

Primary Relay	Backup Relay
1	Relay 1’
2	Relay 1’
3	Relay 6
4	Relay 4
5	Relay4
6	Relay 3, Relay 2
7	Relay11
8	Relay 4
9	Relay 9, Relay 8
10	Relay 11, Relay 8
11	Relay 10
12	Relay 9, Relay 8
13	Relay11
14	Relay 12
15	Relay 14
16	Relay 6
17	Relay2
18	Relay5

Table 3primary backup relay

VII. CONCLUSION

Here we are simulate the network and do some analysis which is load flow analysis and short circuit analysis and take the rated current and short circuit current from that analyses respectively. And design a protection scheme to protect the IEEE 9 bus from the abnormal condition like disturbance in voltage, frequency and power flow

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