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Optimal Location of Star and Delta connected Capacitor Bank for Loss Minimization in a Five Bus Power System

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ABSTRACT – This paper shows the load flow analysis of a five bus ring type power system and the bus at which a capacitor bank (either star or delta type) can be connected so as to minimize the overall active and reactive power losses. The optimal position has been found out for both star and delta connections of capacitor bank to reduce the power losses and also a comparison has been made between both cases regarding the position at which they minimize the losses and the amount of power loss that they minimized. The entire simulation has been done using MATLAB – Simulink software.

KEYWORDS - Load Flow Analysis, Optimum Location of Capacitor Banks, Loss Minimization, Star and Delta Capacitor Banks.

INTRODUCTION

Load flow analysis is a very essential tool in any given power system to analyse the flow of power. Since a practical power system is by default a non – linear system, load flow studies consist of a set of non – linear equations to analyse different power system parameters. The purpose of conducting a load flow study on a power system is mainly to do future planning for extension and upgrades in the power system depending on its current ability to supply the loads that are connected to it. The parameters of importance in a load flow study are voltage, active power, reactive power and load angle. Out of the above four parameters, any two parameters are always known for a given type of bus in the system and the remaining two parameters are found out using various techniques available for the load flow analysis.

There are three types of buses in any power system for load flow studies to be executed:

i). PV Bus or voltage bus i.e. active power and voltage are known for this bus.

ii). PQ Bus or load bus i.e. active and reactive powers are known for this bus.

iii). Slack Bus or reference bus i.e. voltage is always 1 p.u. for this bus.

Consideration of slack bus before starting the load flow analysis of a given power system is important in order to account for the transmission losses that occur in the various parts of the network. Load flow analysis is generally done using single-line diagram of the three phase power system with all quantities preferably represented in per-unit system (machine specifications are generally taken as the base values). Also a very fundamental assumption in these studies is that the power system taken into account is a balanced one. Some of the load flow techniques commonly used is as follows:-

i). Gauss – Siedel Method

ii). Newton – Raphson Method

iii). Fast – Decoupled Method

iv). Decoupled Method

Each of these above methods has their own merits and demerits but generally the second method is more preferred because of greater accuracy and faster convergence of the result with less number of iterations.

One of the many objectives of load flow analysis is to find out the overall active and reactive power losses in the system. It's a very well known fact that in any power system, minimization of these power losses is of prime importance so that maximum power can be delivered to the consumers at the receiving end of the system. One of the common techniques to reduce power losses is the use of capacitor banks that are connected at certain points in the power system. But not every point in a power system is suitable for placement of the capacitor banks and thus, there is always an optimal position in the system where the capacitor bank can be placed for achieving maximum reduction in the power loss. This optimal position of capacitor bank varies depending on the value of capacitors connected, amount of load connected in the power system, number of generating sources in an interconnected system and the mode of connection of the capacitor bank i.e. star or delta connection. The single- line diagram of the power system taken into account is shown below:-

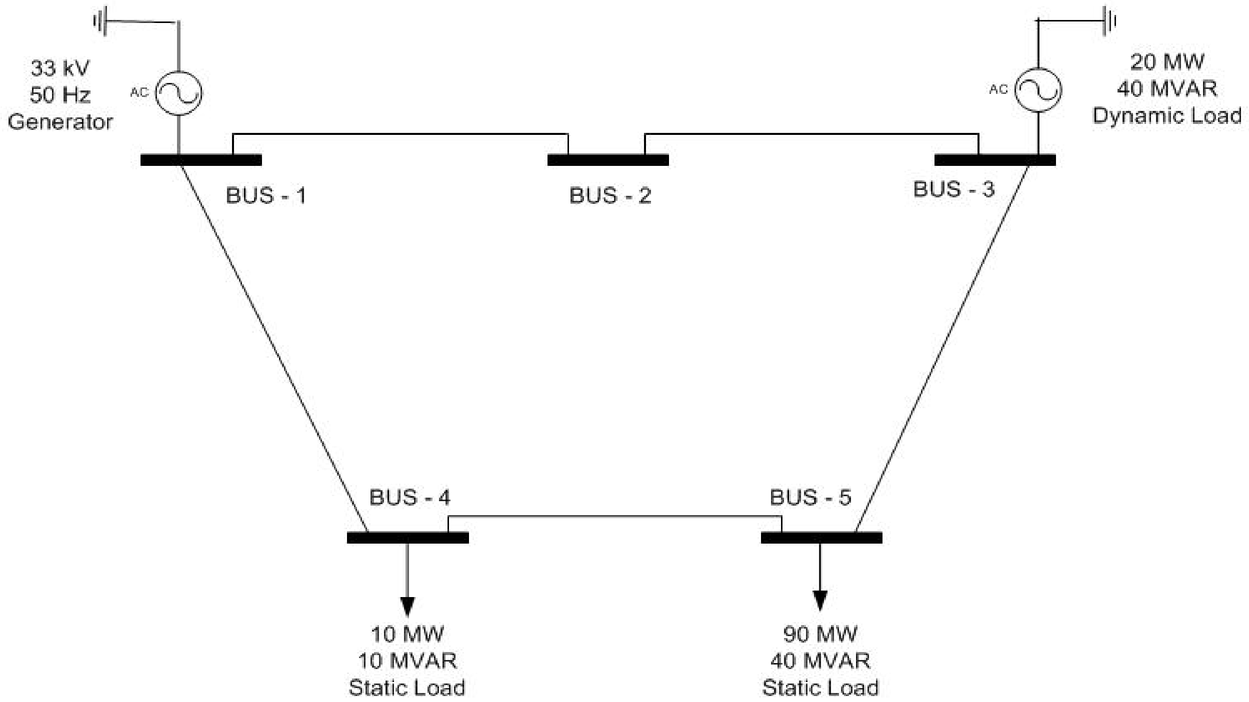

Fig.1. Single Line Diagram of the 5 – bus power system considered for simulation

The capacitor bank can be connected at any of the five buses shown above but only one optimal point exists in this system where connecting the capacitor bank will cause maximum reduction in the power losses. The following section discusses the simulation diagram that has been done in MATLAB – Simulink along with the specification of the components used in the simulation. The optimal point in both star and delta connected capacitor banks has been discussed in the results section followed by a comparative study of the two cases.

SIMULATION AND RESULTS

The simulation diagram as performed in MATLAB – Simulink for the five bus power system is shown as follows:-

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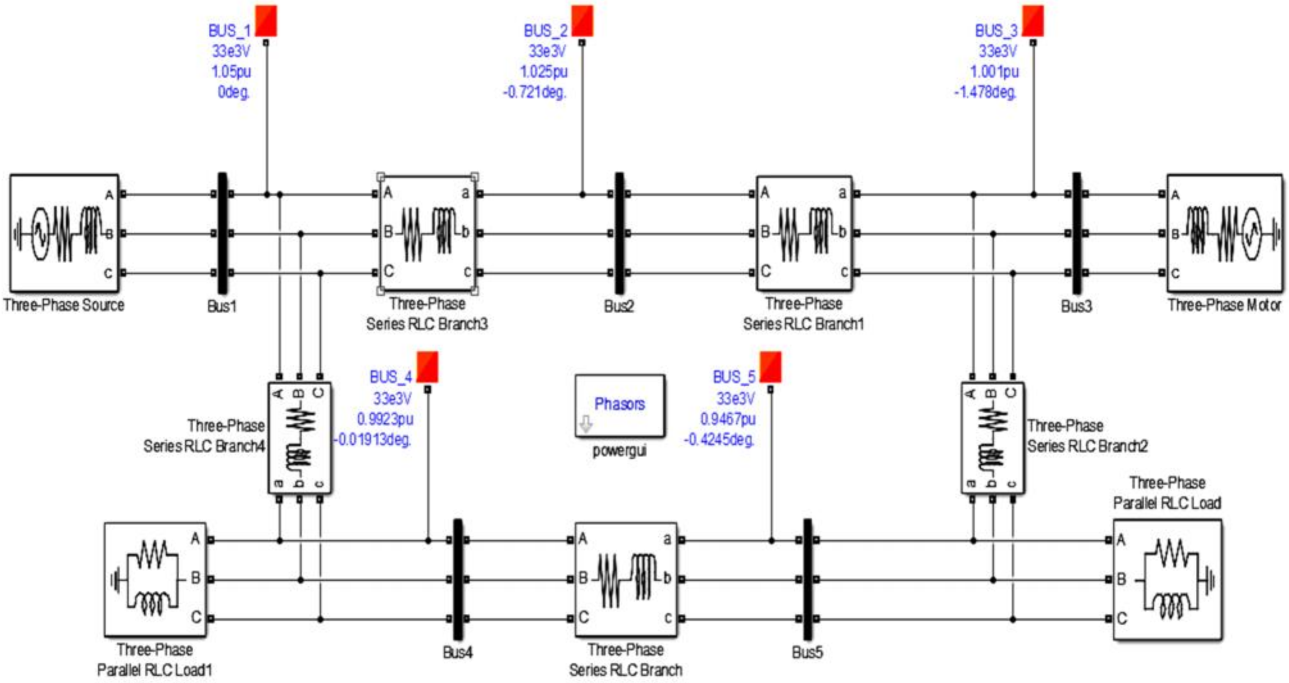

Fig.2. Simulink model of the 5 – bus power system considered for simulation

In the above simulation, the single – line diagram of the five bus power system has been simulated. Each of the transmission lines are represented by their equivalent model i.e. an RL – series circuit. The value of 'R' and 'L' in each line is 1 ohm and 1 milli-henry. The capacitor bank to be connected at the different buses in the above power system is 50 μF/phase for both star and delta connections. The simulation data is shown in the following table:-

Table 1. Simulation data of 5 bus power system considered

BUS. NO	V_{BUS} (kV)	P_{GEN} (MW)	Q_{GEN} (MVAR)	P_{LOAD} (MW)	Q_{LOAD} (MVAR)
1	33	110.17	53.20	-------	-------
2	33	--------	--------	---------	--------
3	33	--------	---------	20	40
4	33	--------	--------	10	10
5	33	--------	--------	90	40

The capacitor banks have been connected at different buses in this power system and the load flow results as obtained in MATLAB – Simulink are shown in the following tables:-

Table 2. Load flow result of 5 bus power system with star connected capacitor bank

Capacitor bank location (50 µF/phase, Y-connected)	Voltage and Load angle Profile at Different buses in pu and degrees respectively										Overall Generation		Overall Losses	
	bus 1		bus 2		bus 3		bus 4		bus 5		P	Q	P	Q
	V (pu)	δ (deg)	V (pu)	δ (deg)	V (pu)	δ (deg)	V (pu)	δ (deg)	V (pu)	δ (deg)	(MW)	(MVAR)	(MW)	(MVAR)
Not connected	1.05	0.00	1.025	-0.72	1.001	-1.48	0.992	-0.02	0.947	-0.42	110.17	53.2	10.17	3.2
bus 1	1.05	0.00	1.025	-0.72	1.001	-1.48	0.992	-0.02	0.947	-0.42	110.17	34.34	10.17	3.2
bus 2	1.05	0.00	1.029	-1.44	1.004	-2.02	0.993	-0.19	0.949	-0.78	110.56	35.2	10.56	3.32
bus 3	1.05	0.00	1.028	-1.24	1.006	-2.53	0.994	-0.35	0.950	-1.13	110.84	36.09	10.84	3.41
bus 4	1.05	0.00	1.027	-1.03	1.005	-2.10	0.995	-0.49	0.953	-1.40	109.59	37.48	9.59	3.01
bus 5	1.05	0.00	1.026	-0.88	1.003	-1.80	0.996	-0.71	0.950	-0.93	109.75	36.08	9.75	3.06

In the above table, for a star capacitor bank, the most optimum position for its placement in the power system is bus number 4 as shown above whereas the least optimal position for the star capacitor bank is bus number 3. Also the voltage at all buses is relatively more stable when the capacitor bank is connected at bus 4 as compared to the capacitor bank being placed at all the other buses.

Table 3. Load flow result of 5 bus power system with delta connected capacitor bank

Capacitor bank location (50 µF/phase, Δ-connected)	Voltage and Load angle Profile at Different buses in pu and degrees respectively										Overall Generation		Overall Losses	
	bus 1		bus 2		bus 3		bus 4		bus 5		P	Q	P	Q
	V (pu)	δ (deg)	V (pu)	δ (deg)	V (pu)	δ (deg)	V (pu)	δ (deg)	V (pu)	δ (deg)	(MW)	(MVAR)	(MW)	(MVAR)
Not connected	1.05	0.00	1.025	-0.72	1.001	-1.48	0.992	-0.02	0.947	-0.42	110.17	53.2	10.17	3.2
bus 1	1.05	0.00	1.025	-0.72	1.001	-1.48	0.992	-0.02	0.947	-0.42	110.17	-3.38	10.17	3.2
bus 2	1.05	0.00	1.037	-2.88	1.009	-3.11	0.995	-0.54	0.952	-1.51	112.78	-1.12	12.78	4.01
bus 3	1.05	0.00	1.032	-2.30	1.016	-4.68	0.997	-1.04	0.957	-2.56	114.3	1.54	14.3	4.49
bus 4	1.05	0.00	1.031	-1.66	1.012	-3.37	1.001	-1.44	0.964	-3.39	110.27	5.5	10.27	3.23
bus 5	1.05	0.00	1.028	-1.20	1.007	-2.46	1.004	-2.11	0.956	-1.96	110.25	1.46	10.25	3.22

In the above table, for a delta capacitor bank, the most optimum position for its placement in the power system is bus number 1 as shown above whereas the least optimal position for the star capacitor bank is bus number 3. Also the voltage at all buses is relatively more stable when the capacitor bank is connected at bus 1 as compared to the capacitor bank being placed at all the other buses.

CONCLUSION

In this paper, the load flow analysis of a custom made 5 bus power system has been done in MATLAB – Simulink and the optimal location for both star and delta connected capacitor banks for minimization of line flow losses has been done. Also on comparing both cases, it was found that star connected capacitor bank provides better loss minimization as compared to delta capacitor bank as the minimum loss in 'P' and 'Q' for star capacitor bank are 9.59 MW and 3.01 MVAR respectively whereas for delta capacitor bank the values for the same are 10.17 MW and 3.20 MVAR respectively. The same procedure can be repeated for different values of capacitance per phase.

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