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OPTIMAL SIZING AND ALLOCATION OF STATCOM FOR HIGH VOLTAGE TRANSMISSION SYSTEM VOLTAGE STABILITY IMPROVEMENT USING PSO ALGORITHM

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High voltage transmission system, Particle Swarm Optimization, Reactive power, STATCOM, Voltage Stability.

ABSTRACT

Modern power system faces many challenges due to daily increasing complexity in function and structure. In the recent past, one of the problems is the instability of the power system due to the lack of new generation and transmission facilities and the operation of existing facilities run by the increasing load demand. Also the main problem to voltage instability is the limit of reactive power. Voltage instability occurs due to the increasing load demand and requirement in reactive power control. The consequence of voltage instability may cause progressive and uncontrollable decline in voltage. Now the reactive power limit and voltage stability can be improved by using FACTS devices. In this paper, Static Synchronous Compensator (STATCOM) which is a shunt connected FACTS controller is used to improve the voltage stability of Yangon Electric Supply System. The location and sizing of STATCOM is executed by Particle Swarm Optimization (PSO) algorithm. Modelling and simulations are executed using MATLAB/Simulink software. The simulation results show that the application of STATCOM can improve the system voltage stability under normal condition and under contingency condition.

I. INTRODUCTION

Voltage stability refers to a power system's capacity to maintain constant, acceptable voltages across all buses in the system under normal operating conditions and after contingency condition [1]. Voltage stability is an important aspect of improving the safety and reliability of power systems. Reactive power (VAR) compensation is that the management of reactive power to boost the performance of AC system. The regulation of reactive power (VAR) to improve the performance of an AC system is referred to as reactive power compensation. In the presence of a disturbance, reactive power compensators are widely employed to regulate load voltage. If voltages following disturbances are near to voltages under normal operating conditions, the power system voltage is stable. When a voltage drops out of control due to equipment failure or a sudden increase in load, the power system becomes unstable. Voltage stability is generally a local issue, but the consequences of voltage instability have significant implications for power systems. Voltage collapse and a blackout are the result of this impact. Voltage and reactive power regulation must be appropriately done to keep voltage at all buses within acceptable limits for efficient and reliable power system operation.

It is critical that voltage control be accomplished by identifying suitable compensating devices. In this paper, Static Synchronous Compensator (STATCOM) as the FACTS device is incorporated to control the voltage stability on transmission lines. The optimization of STATCOM device is executed by Particle Swarm Optimization. It is evolutionary computation technique that can be used to solve the FACTS sizing and allocation problem. The main goal of this paper is to show the application of PSO for the optimal allocation of a STATCOM in a transmission system. Yangon Electricity Supply System is used as an example to the methodology. The model is built in MATLAB, and the results show the performance contrast.

II. VOLTAGE STABILITY

For voltage stability analysis, the continuing power flow approach is utilized. The only way to protect your system from voltage dips is to reduce the reactive power load or add additional reactive power before the voltage dip point is reached. Static-voltage stability margins are usually improved by providing appropriate reactive power support at the weakest bus. With static voltage stability, slowly developing changes occur in the network, ultimately leading to a lack of reactive power and a drop in voltage. The voltage collapse phenomenon in power systems has become one of the most important concerns in the power industry [2].

The most effective way to increase the system's voltage stability and power transfer capability is to use reactive power compensation. The voltage bus level is controlled by controlling the generation, consumption, and flow of reactive power. The reactive power assistance that a bus can receive determines its voltage stability and load ability in the power system. The actual and reactive power losses increase rapidly as the system approaches the Maximum Loading Point. As a result, sufficient reactive power supports must be provided in order to ensure voltage stability [2].

III. STATIC SYNCHRONOUS COMPENSATOR (STATCOM)

A Flexible AC Transmission System (FACTS) is a system that combines power electronic-based or other static controllers to provide better power stream control and improved dynamic dependability. STATCOM is one of the most important shunt FACTS controllers, with a wide range of applications in the electric utility industry. Since the 1980s, STATCOM has played an important role in the force sector, and it is regarded as one of the most important breakthroughs in the future force framework. STATCOM works on the principle that a voltage source inverter creates a controllable AC voltage source behind a reactance, causing a dynamic and receptive force exchange between the STATCOM and the transmission system line in a similar way to a synchronous condenser. Self-commutated converters with sections with current blocking capabilities are used in the most recent methodology for strong state power compensators. A STATCOM can provide rapid capacitive and inductive pay and control its yield current independently of the AC framework voltage. Even at low framework voltage, STATCOM can maintain full yield current range. Figure 1.demonstrates the schematic arrangement of STATCOM [3].

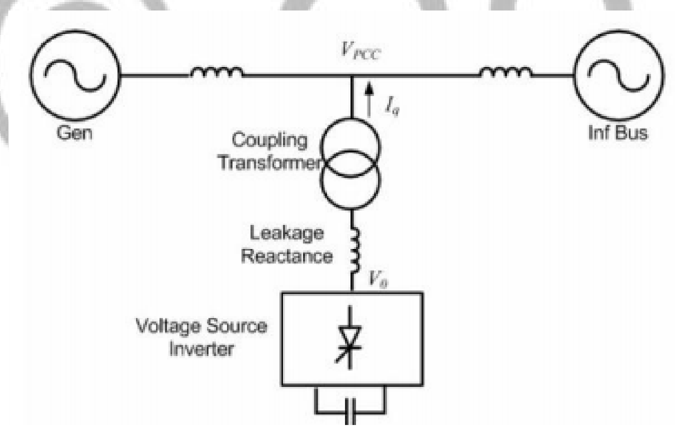

Fig.1 Schematic Arrangement of STATCOM

Resistance, leaky inductance, and VSI and DC capacitors make up STATCOM. Resistance and inductance serve as an attractive coupling to the frame. They provide isolation between the inverter circuit and the frame circuit. The DC electrical condenser provides a relentless voltage and functions as an influence provide. The STATCOM can keep up full yield current range even at low framework voltage, which likewise makes it more powerful than SVC in enhancing the transient steadiness. Because of the use of VSC, STATCOM may swap genuine force with lattice bi-directionally and control both responsive force and genuine force autonomously, which is not possible with an SVC. In inductive and capacitive mode, the terminal voltage V bus is equal to the sum of the inverter voltage V STATCOM and the voltage crosswise across spillage reactance V- L and resistance. STATCOM will give responsive energy to the framework if the STATCOM yield voltage V STATCOM is equal to the transport terminal voltage V bus and V STATCOM is larger than V bus. On the off chance that V_STATCOM is littler than V_bus, STATCOM retains receptive force from force framework. If V STATCOM and V bus are equal, then no force will be traded; instead, STATCOM will operate in coasting mode. Figure 2.demonstrates working standard operation of STATCOM [3].

There are a variety of STATCOM control methods available, but standard Proportional-Integral (PI) controllers are used in many applications. But, in traditional PI controller we obtain PI gains via a trial-and-error approach or extensive studies with a tradeoff of performance and applicability. The error should be corrected using the PI controller. It is used as DC voltage controller which regulates DC capacitor voltage. The PI controller requires an accurate linear mathematical model with zero steady-state error. Reference source current is estimated by regulating the DC capacitor voltage [3].

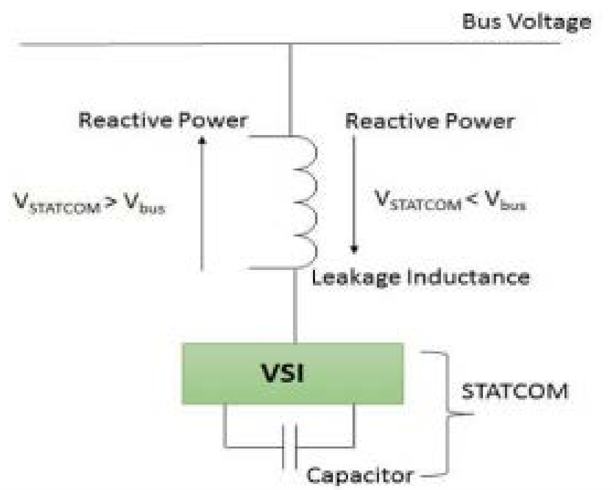

Fig.2 Working Standard Operation ofSTATCOM

When the force framework working situation (e.g., burdens or transmissions) changes, the STATCOM with changed PI control settings may not come to the desired and worthy reaction in the force framework. A versatile PI control strategy is with a specific end goal to get the coveted reaction and to abstain from performing experimentation studies to discover appropriate parameters for PI controllers when another STATCOM is introduced in a force framework. With this versatile PI control technique, the dynamical self-change of PI control parameters can be figured it out [3].

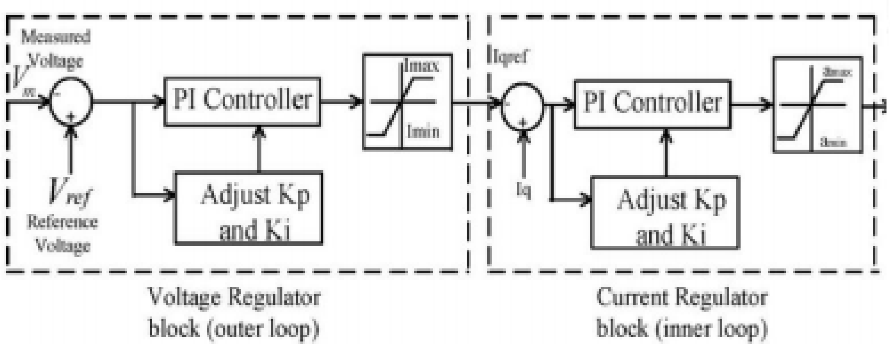

Fig.3 Voltage Regulator and Current Regulator Control with PI Controllers

The following is a description of the adaptive voltage-control approach for STATCOM:

1) Determine the voltage on the bus (Vm) (t)
2) Compare the Vm(t) and Vss voltages, with Vss being the steady state voltage. If the difference between these two is not zero, Kp v and Ki v will self-adjust to equal zero.
3) Iqref is compared to Iq in the inner loop in the same way. If there is a discrepancy between these two, Kp- i and Ki-i will automatically adapt to find the appropriate angle, allowing the precise quantity of reactive power to be injected into the power system network.

IV. PARTICLE SWARM OPTIMIZATION ALGORITHM

In the basic particle swarm optimization (PSO) algorithm, particle swarm consists of "n" particles, and the position of each particle stands for the probable solution in D-dimensional space. The particles change its order or condition according to the following three principles: (i) To keep its inertia (ii) to change the condition according to its most optimist position (iii) to change the condition according to the swarm's most optimist position.

The most optimist particle's position during movement (individual experience) and the most optimist particle's position in its surroundings both exaggerate the position of each particle in the swarm (near experience). The most idealism position of the surrounding is equivalent to the one of the whole most optimist particle when the entire particle swarm is surrounding the particle; this algorithm is known as the full PSO. When a restricted environment is used in the algorithm, it is called a partial PSO [4].

Each particle can be represented by its current velocity and position, the optimal position for each individual, and the most optimistic position in the environment. The speed and location of each particle in the partial PSO fluctuate according to the following equality [4].

$$v_{id}^{k+1} = v_{id}^{k} + c_1 r_1^k \left(pbest_{id}^k - x_{id}^k\right) + c_2 r_2^k \left(gbest_d^k - x_{id}^k\right)$$

$$x_{id}^{k+1} = x_{id}^{k} + v_{id}^{k+1}$$

In this equality, v_{id}^k and x_{id}^k stand for separately the speed of the particle "i" at its "k" times and the d-dimension quantity of its position; $pbest_{id}^k$ represents the d-dimension quantity of the individual "i" at its most optimist positional its "k" times. $gbest_d^k$ is the d-dimension quantity of the swarm at its most optimist position. In order to evade particle being far away from the searching space, the speed of the particle fashioned at its each direction is limited between -V_{dmax}, and V_{dmax}. If the number of V_{dmax} is too big, the solution is far-off from the best, if the number of V_{dmax} is too small, the solution will be the local optimism; C_1 and C_2 represent the speeding figure, regulating the length when flying to the most particle of the whole crowd and to the most optimist individual particle. If the shape is too small, the particles are probably far away from the objective and the shape is too large. Particles can suddenly fly into or beyond the target field.

V. STUDY ON YANGON ELECTRIC SUPPLY SYSTEM

In this study, the voltage stability improvement by STATCOM is studied for Yangon Electricity Supply System. Yangon is the largest load center in Myanmar and thus voltage stability problem must be encountered in system planning and operation. In transmission level, 230 kV system is used. The selected system is 14 bus system consisting of 7 generators, 14 loads and 14 transmission lines. This system is tested without and with STATCOM. The single line diagram for this system is shown in Figure 4.

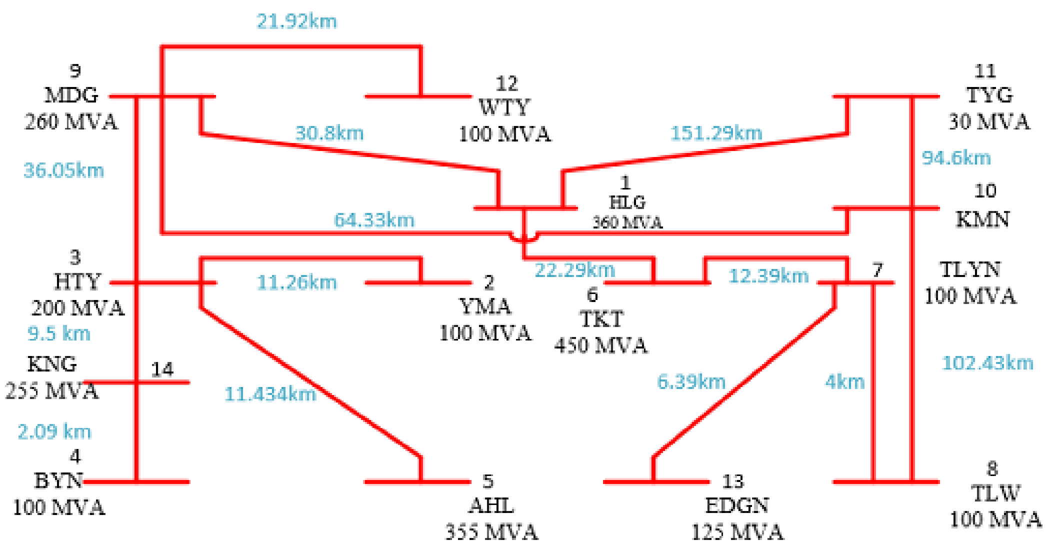

Fig.4 Single Line Diagram for Yangon Electricity Supply System

For detail study, the data collection is carried out during 2021. The simulations are carried out based on the actual collected data. The following tables expressed the transmission line and bus data of the selected system.

Table 1 TRANSMISSION LINE DATA

No.	Name	Line Length(km)	No. of Circuit	Conductor Size
1	Hlawga-Thaketa	22.29	single	795mcm
2	Hlawga-Tharyargone	151.29	single	795mcm
3	Myaungdagar-Wartayar	21.92	single	605mcm
4	Ywama-Hlaingtharyar	11.26	Double	605mcm
5	Hlaingtharyar-Ahlone	11.434	single	605mcm
6	Hlaingtharyar-Myaungdagar	36.05	single	605mcm
7	Thaketa-Thalyin	12.39	double	605mcm
8	Thalyin-East Dagon	19.96	single	605mcm
9	Thalyin-Thilawa	4	double	605mcm
10	Kamarnat-Thilawa	102.43	double	605 mcm

11	Myaungdagar-Kamarnat	64.33	single	605mcm
12	Kamarnat-Tharyargone	94.6	single	605mcm
13	Hlaingtharyar-Kanaung	9.5	single	605mcm
14	Kanaung-Byintnaung	2.09	single	605mcm

Table 2 BUS DATA WITH POWER GENERATIONS/DEMANDS

Bus No.	Bus Name	Bus Type	Maximum Power Demand/Generation	
			P (MW)	Q (MVAR)
1	Hlawga (HLG)	Generator	11.25	-7.63
2	Ywama (YMA)	Generator	199.1	93.13
3	Hlaingtharyar (HTY)	Load	151.1	73.18
4	Byintnaung (BYN)	Load	104.5	50.62
5	Ahlone (AHL)	Generator	90.61	40.24
6	Thaketa (TKT)	Generator	9.58	-6.48
7	Thalyin (TLYN)	Load	43.62	21.16
8	Thilawa (TLW)	Generator	130.4	51.02
9	Myaungdagar (MDG)	Swing	97.44	29.8
10	Kamarnat (KMN)	Load	70.39	34.12
11	Tharyargone (TYG)	Generator	90.94	20.46
12	Wartayar (WTY)	Load	43.31	21.01
13	East Dagon (EDGN)	Load	107.2	51.94
14	Kanaung (KNG)	Load	106.8	51.6

VI. WITHOUT STATCOM

For the modelling of the system, the total connected load is 1396.98 MW in sample day. For contingency condition, three phase fault and load turn-off are applied to the bus of Tharketa. Line outage is carried out at Tharketa- Hlawga transmission line where the flow of power is largest in the modelled transmission system. Generation trip is selected to Ywama bus since the power generation is largest in the system. These conditions are shown in Figure 5.

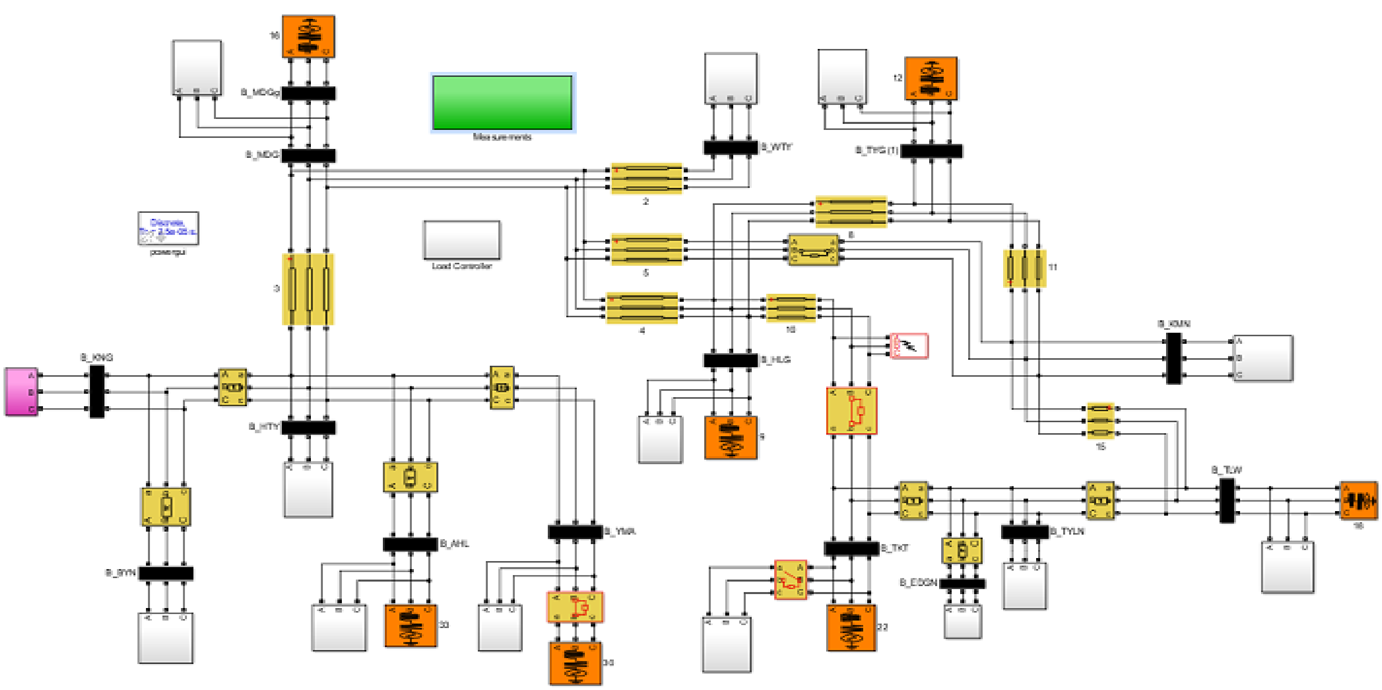

Fig.5 Simulink Model of Yangon Electricity Supply System for Voltage Stability Study

The simulation results of generators and load bus voltages with different load in normal conditions are shown in Figure 6. Table 3 shows the result of voltage, real and reactive power at generator and load buses in normal load conditions.

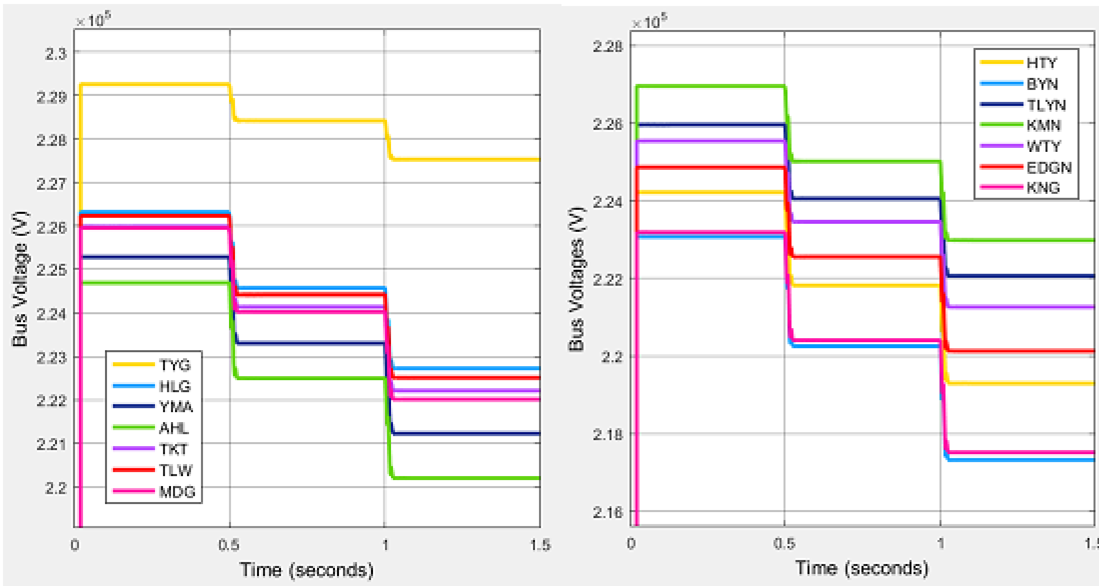

Fig.6 Generator and Load Bus Voltages with Different Load Condition

Table 3 THE VOLTAGE, REAL AND REACCTIVE POWER AT GENERATOR AND LOAD BUSES

SN	Bus Name	Voltage (kV)			Real Power (MW)			Reactive Power (MVAR)		
		Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.
1	Hlawga (HLG)	226.3	224.6	222.7	7.13	9.25	11.25	-11.24	-9.46	-7.63
2	Ywama (YMA)	225.3	223.3	221.2	118.7	158.9	199.1	50.7	71.74	93.13
3	Hlaingtharyar (HTY)	224.2	221.8	219.3	90.09	120.6	151.1	43.62	58.41	73.18
4	Byintnaung (BYN)	223.1	220.3	217.3	62.84	83.78	104.5	30.38	40.53	50.62
5	Ahlone (AHL)	224.7	222.5	220.2	54.23	72.46	90.61	20.11	30.12	40.24
6	Thaketa (TKT)	226	224.1	222.2	5.99	7.81	9.58	-9.91	-8.24	-6.48
7	Thalyin (TLYN)	226	224.1	222.1	25.87	34.69	43.62	12.45	16.8	21.16
8	Thilawa (TLW)	226.2	224.4	222.5	77.27	103.8	130.4	23.86	37.32	51.02
9	Myaungdagar (MDG)	225.9	224	222	58.15	77.76	97.44	9.72	19.66	29.8
10	Kamarnat (KMN)	227	225	223	41.68	55.95	70.39	20.16	27.09	34.12
11	Tharyargone (TYG)	229.3	228.4	227.5	53.7	72.25	90.94	0.75	10.36	20.46
12	Wartayar (WTY)	225.5	223.5	221.3	25.78	34.5	43.31	12.4	16.71	21.01
13	East Dagon (EDGN)	224.9	222.5	220.1	63.85	85.53	107.2	30.87	41.38	51.94
14	Kanaung ()	223.2	220.4	217.5	64.13	85.55	106.8	30.98	41.33	51.6

As shown in the simulation results, the bus voltages decreased with increased in load power demand. Under maximum load condition, all generator bus voltages are within the stability limit, but some load bus voltages are below the lower voltage limit. The application of STATCOM can improve the voltage stability of the system.

VII. APPLICATION OF PSO FOR ALLOCATION AND SIZING OF STATCOM

To enhance system voltage stability, optimum location and parameters settings of STATCOM is obtained using PSO algorithm. The main parameters are the magnitude of the output voltage V_{VR} and the angle δ_{VR}, these parameters are taken to control the device performance. For the allocation and sizing of STATCOM in the system, simulations are carried out by using PSO technique with Newton-Raphson power flow method, for losses minimizing and improving voltage profile. The main parameters with PSO algorithm are:

- w_start = 1; %Initial inertia weight's value
- w_end = 0.20; %Final inertia weight
- N = 50 % no. of particles
- iter = 200 % no of iterations

With PSO algorithm, the simulation results show the optimal location is bus 10 with STATCOM capacity of 40 MVAR. The following table shows the comparison of simulation results for STATCOM allocation by PSO.

Table 4 COMPARISON OF SIMULATION RESULTS FOR STATCOM ALLOCATION BY PSO

Parameters	With STATCOM	Without STATCOM
Total Active Power Losses (MW)	5.508 MW	5.713 MW
Total Reactive Power Losses (MVar)	136.04 MVar	141.26 MVar
Max; Active Power Losses (MW)	1.20 MW	1.25 MW
Max; Reactive Power Losses (MVar)	30.30 MVar	31.58 MVar
Min; Voltage Magnitude (pu)	0.966 at Bus 10	0.939 at Bus 10

As shown in table, the total and maximum value of active power losses and reactive power losses are reduced with the application of STATCOM at the selected bus. At Bus 10, minimum voltage magnitude is increased from 0.939 pu to 0.966 pu when the STATCOM is connected to the system.

VIII. SIMULATION OF ANALYSIS OF SYSTEM WITH STATCOM

The STATCOM capacity 40 MVar is connected at bus 10 in Simulink model is shown in Figure 7. For voltage stability study under different load conditions, the simulation is executed and the results are shown in Figure 8.

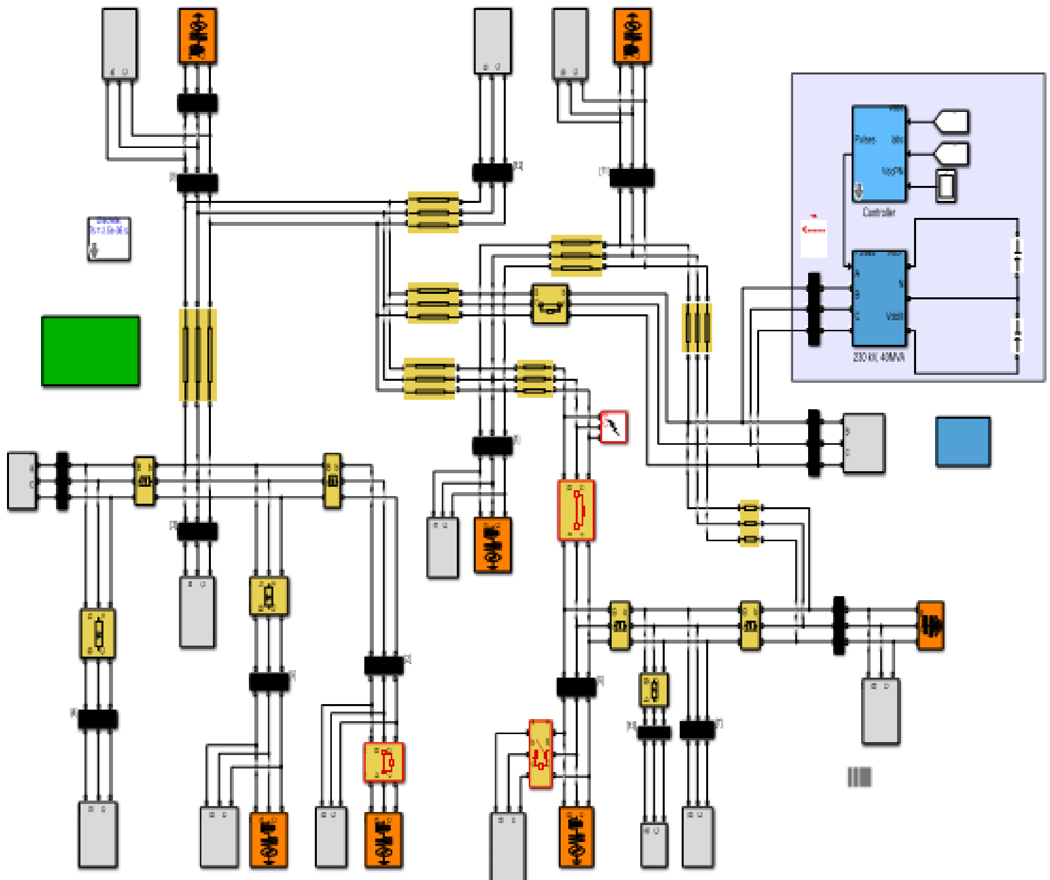

Fig.7 Simulink Model for Voltage Stability Study with STATCOM

As shown in the simulation results, the bus voltages are increased under different load conditions compared to without STATCOM case. Under maximum load condition, all generator bus voltages as well as load bus voltages are within the stability limits. Thus, the application of STATCOM can improve the voltage stability of the system under different load conditions.

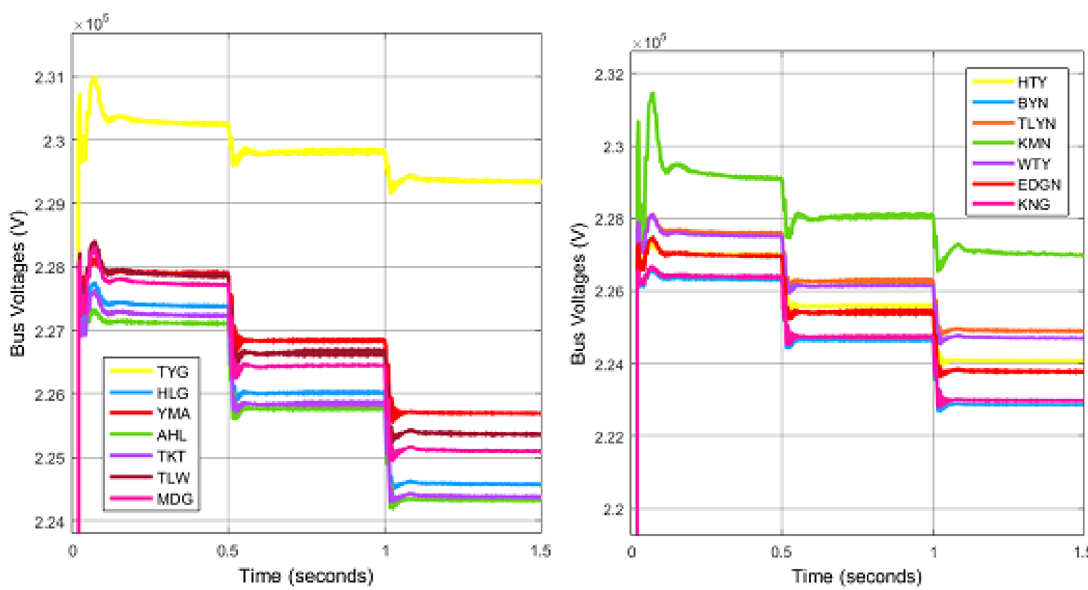

Fig.8 Generator and Load Bus Voltages with STATCOM

For steady state condition, the simulations are carried out for minimum load, average load and maximum load conditions. The bus voltages are decreased as the load increased. Without STATCOM, the bus voltages are much lower than the nominal values and in maximum load condition, some bus voltages are below the lower voltage limits. With STATCOM, the bus voltage profiles are improved and all bus voltages are within the voltage regulation limits even under maximum load condition.

For voltage stability study under contingency conditions, the load power demands are set at maximum value. The contingency conditions are created as in without STATCOM case. For contingency condition, the simulations are carried out for three-phase fault, line outage, load turn-off and generator trip. The comparison of the simulation results for contingency conditions for without and with STATCOM are shown in Figure 9.

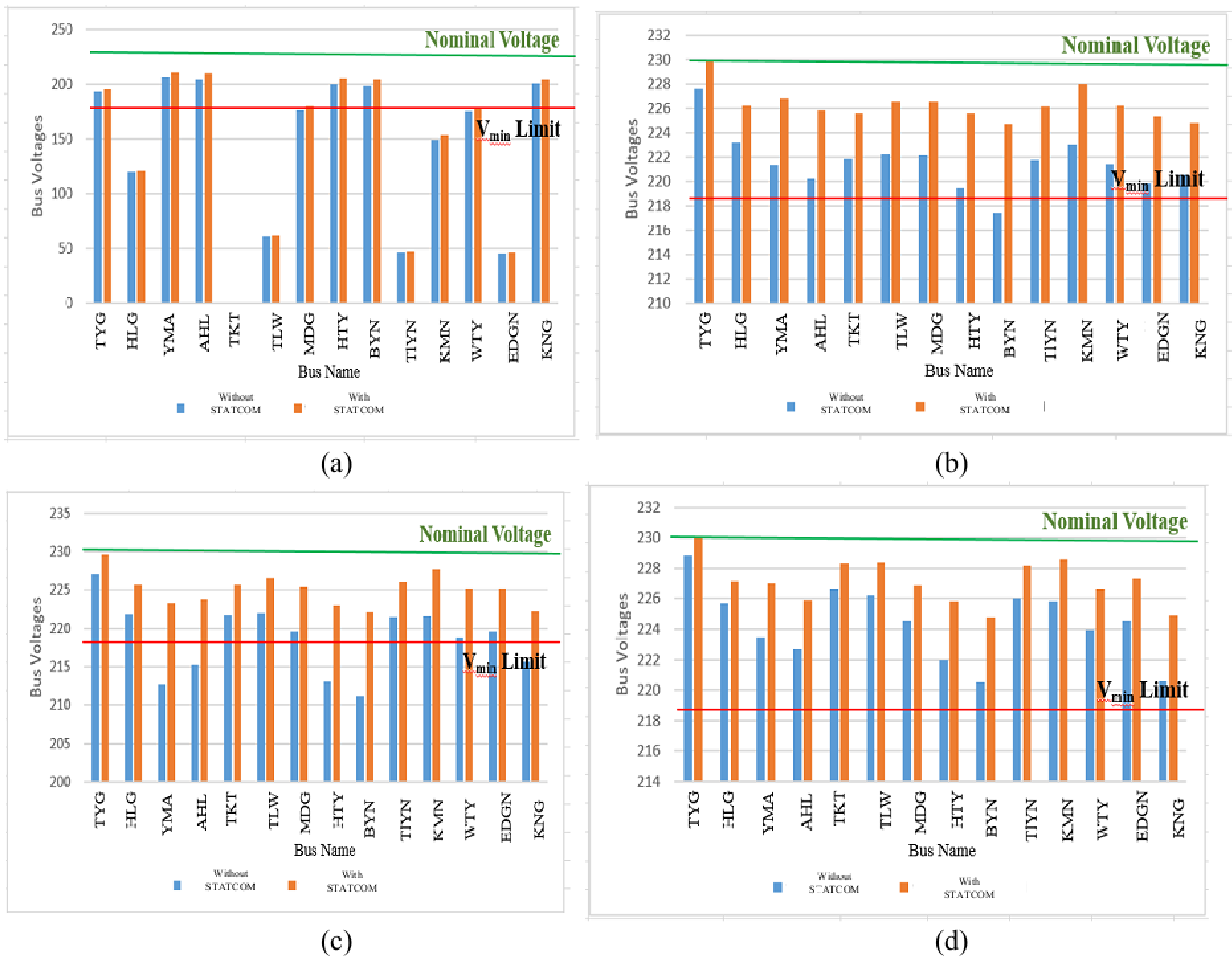

Fig.9 Comparison of Bus Voltages for without STATCOM and With STATCOM: (a) Three Phase Fault, (b) Line Outage , (c) Generator Trip , (d) Load Turn-off

With three phase fault, the faulted bus voltage (Tharketa bus) is approach to zero and all other remaining bus voltages are decreased for both without and with STATCOM. With line outages, the bus voltages are decreased, but the application of STATCOM can maintain the bus voltages within limits. With load turn-off, all bus voltages increased and are within the voltage limits for both cases. With generator trip, the bus voltages decreased and most the bus voltages drop below the minimum limit in without STATCOM case. With STATCOM, all bus voltages are improved and within the voltage limits.

Conclusion

Presently the application of STATCOM in the transmission system for voltage regulation by fast and efficient reactive power support has been discussed. The voltage stability analysis is made for Yangon Electricity Supply System. The voltage stability analysis of the system is studied under different loading condition and under contingency condition with maximum loading. From the result, it is observed that bus voltage magnitude has been improved by providing the reactive power support at the specified bus supported by PSO algorithm. It has been observed that after the implementation of Particle Swarm Optimization Algorithm in the test system, there is reduction in active and reactive power loss and voltage stability of the system is significantly improved. For further study, the voltage stability improvement of the transmission system should be executed using STATCOM with the intelligent control methods.

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