Ac Power Flow Control of Grid by Series D-Fact

Er.Qasim kamil Mohsin, Jyoti Shrivastava

Abstract*— *The power interconnection is getting increasingly congested so to control power flow of transmission grid, to limit loop flows, and also the capacity of transmission line can be increased by use of flexible ac transmission systems (FACT) devices. But high cost and reliability concerns have limited the FACT solutions. This paper introduces the concept of Distributed SERIES FACTS (D-FACTS) as an alternative approach to realizing cost-effective power flow control by way of distributed series impedance (DSI) and a distributed static series compensator (DSSC). D-FACTS can be clipped on power line and it can dynamically and statically change the impedance of the line so as to control and increase capacity of power flow. D-FACTS provides higher performance and lower cost method for enhancing T&D system reliability and controllability, improving asset utilization and end-user power quality, while minimizing system cost and environmental impact.

Index Terms*— *Power flow control, FACTS device system, Distributed flexible AC transmission systems

I. INTRODUCTION

The most significant issue in terms of grid utilization is that of active power flow control. Utility customers purchase real power, megawatts and MW-Hrs, and not voltage or reactive power. Thus, control of how and where real power flows on the network is of critical importance, and is the underlying premise behind the realization of an electricity market. Congested networks limit system reliability and constrain the ability of low cost generators to provide interested customers with low-cost power. The situation is considerably aggravated when one sees that neighboring lines are running below capacity, but cannot be utilized, while uncontrolled "loop-flows" result in overloads on existing lines. Active power flow control requires cost-effective "series VAR" solutions, that can alter the impedance of the power lines or change the angle of the voltage applied across the line, thus controlling power flow. Series reactive compensation has rarely been used other than on long transmission lines, mainly because of high cost and complexity of achieving voltage isolation and issues related to fault management[1].

There is general consensus that the future power grid will need to be smart and aware, fault tolerant and self-healing, dynamically and statically controllable, and asset and energy efficient. The accepted and technically proven approach for realizing a smart grid, in particular achieving control of active power flow on the grid, has been through the use of Flexible ac Transmission Systems or FACTS devices, such as STATCON, SVC, SSSC and UPFC can be inserted in series or shunt, or a combination of the two, to achieve a myriad of control functions, including voltage regulation, system damping and power flow control.

Typical FACTS devices can operate at up to 345 kV and can be rated as high as 200 MVA. Even though FACTS technology is technically proven, it has not seen widespread commercial acceptance due to a number of reasons.

i) High system power ratings require the use of custom high power GTO or GCT devices with significant engineering effort- raises first cost. ii) High fault currents (60 000 Amps) and basic insulation requirements (1000 KV) stress the power electronics system, especially for series systems that are required for power flow control. iii) Utilities require higher reliability levels than what they have so far experienced with FACTS devices (primarily as a result of high MTTR). iv) Required skilled work force in the field to maintain and operate the system is not within a utility's core competency normally. v). High total cost of ownership,

The concept of a Distributed Series Impedance (DSI) that can realize variable line impedance, helping to control active power flow is used to illustrate the feasibility of a Distributed FACTS or D-FACTS approach. The concept can be further extended to realize a Distributed Static Series Compensator or DSSC, using modules of small rated (10kVA) single phase inverters and a single turn transformer (STT), along with associated controls, power supply circuits and built-in communications capability[1],[2],[4].

These concepts are discussed in detail, along with the benefits and issues associated with such an application.

II. PRINCIPLES OF ACTIVE POWER FLOW

For controlling power flow on transmission lines, the series elements clearly have the highest potential and impact. The real P and reactive Q power flow, and along a transmission line connecting two voltage buses is governed by the two voltage magnitudes V_1 and V_2 and the voltage phase angle difference,

$\delta = \delta 1 - \delta$

$$P12 = \frac{V1\ V2}{XL} \sin\delta \qquad (2.1)$$

$$Q12 = \frac{V1\ V2}{XL} \cos\delta - \frac{V1^2}{XL} \qquad (2.2)$$

Where X_L is the impedance of the line, assumed to be purely inductive. Control of real power flow on the line thus requires that the angle or the line impedance X_L be changed. A phase shifting transformer can be used to control the angle. This is an expensive solution and does not allow dynamic control capability. Alternatively, a series compensator can be used to increase or decrease the effective reactive impedance XL of the line, thus allowing control of real power flow between the two buses. The impedance change can be effected by series injection of a passive capacitive or inductive element in the line. Alternatively, a static inverter can be used to realize a controllable active loss-less element such as a negative or positive inductor or a synchronous fundamental voltage that is orthogonal to the line current [3], [4].

Transmission and sub-transmission systems today tend to be increasingly meshed and inter-connected. The ability to

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switch out faulted lines without impacting service has a dramatic impact on system reliability. However, in such interconnected systems, current flow is determined by line impedances, and the system operator has very limited ability to control where the currents flow in the network. In such systems, two lines to reach thermal capacity limits the capacity of the entire network, even as other lines remain considerably under-utilized. For example, if series reactive compensation could be applied to the two line or one of them .system in an additional 20% MW of power could be transferred between the two busses by changing the line reactance by 20%. Series FACTS devices can control power flow by varying the parameters in equation (2.1). Such devices typically require a break in the line and a high voltage platform, further adding to the cost and complexity. What is clearly required is a cost-effective, scalable and controllable series impedance device that can be incrementally deployed, and that features high reliability and availability. A distributed approach to implementing series FACTS devices is discussed next.

Transmission line 132 kV, 0.445Ω/KM, 120MVA [5] and for distance 20 Km, X_L=8.9 Ω, the change in power transfer by change the value of XL as shown in Table 1&2.

TABLE (1) Increase in power with the decrease in the reactance of line by X_C

Voltage (KV)	Line reactance X_L (Ω)	Add XR (Ω)	Load angle δ(Deg)	Transfer power (MW)	
				Without X_C	With X_C
132	8.9	1.78	3.51°	120	149.8
132	8.9	0.68	3.51°	120	129.7

TABLE (2) decreses in power with the increase in the reactance of line by X_R

Voltage(KV)	Line reactance X_L (Ω)	Add XR (Ω)	Load angle δ(Deg)	Transfer power (MW)	
				Without X_R	With X_R
132	8.9	1.78	3.51°	120	99.6
132	8.9	0.68	3.51°	120	111

III. DISTRIBUTED SERIES D-FACTS

Distributed FACTS or D-FACTS solution, can offer significant benefits over conventional FACTS technology. The series injection of impedance or voltage at each module can be accomplished using a single turn transformer (STT), which uses the line conductor itself as a winding of the transformer. By floating the device on the wire, all issues of voltage rating and insulation are avoided. The redundancy provides for uninterrupted operation in the event of a unit failure, giving high reliability and availability. The STT allows handling of high levels of fault current, typically a challenging problem for series connected devices. The target power rating of 10 KVA allows the use of readily-available high-volume low-cost components and manufacturing technologies to realize very low unit module cost. The devices can be incrementally deployed as needed, providing an unprecedented level of scalability. Finally, the DSI device can be clamped on to an existing power line, simplifying the installation and commissioning process. These properties demonstrate a unique level of functionality for series D-FACTS devices that is radically different from conventional FACTS devices. Implementation of a Distributed Series Impedance is discussed next

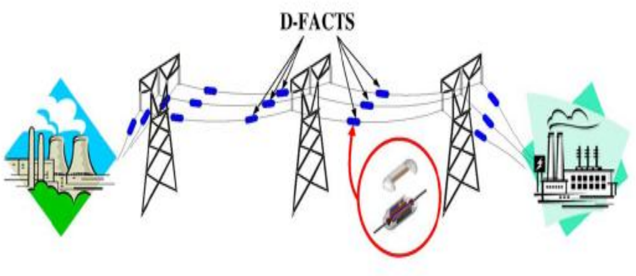


Fig. 1. D-FACTS modules on power lines.

A. *Distributed Series Impedance-Principle of Operation :*

a simple implementation of a DSI uses three switches, a capacitor and an inductor, in conjunction with the STT as shown in Fig.2. Static switches are preferred for fast response under fault conditions. The STT is designed with a large number of secondary turns, say 50:1 . The STT is normally bypassed by the normally-closed electro-mechanical switch SM, while opening it allows injection of the desired impedance. Switch S1 is closed to inject an overall inductance, while S2 is closed to inject capacitance XC. Control power can be derived from the line itself using a current transformer. If N devices are used in series along the power line, one can realize 2N discrete values of line impedance as ,If N was a large number, say 100, the impedance could be changed with 0.5% resolution, approximating a linearly varying line impedance. Operation of individual modules would need to be coordinated with a communications link, and would be controlled by the system operator [6]. This would clearly require establishing a communications infrastructure that could cost-effectively connect individual modules and the SCADA/EMS systems.

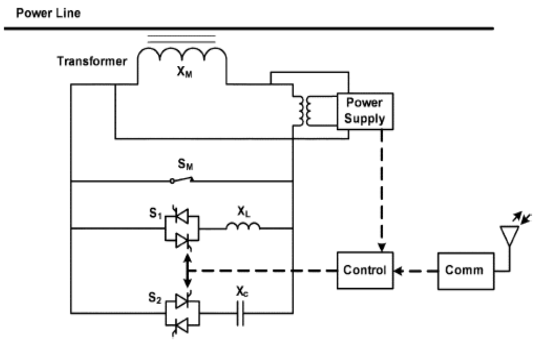


Fig. 2.Circuit schematic of DSI .

B. *Distributed Series Reactor-Principle of Operation*

Fig.3. shows an even simpler implementation of a Distributed Series Reactor (DSR), that can be deployed in interconnected or meshed power networks, and can be autonomously controlled at the individual module level, using a simple control strategy with no communications to dramatically increase the capacity of the overall power grid [7]. As in the

case of the DSI, a normally closed electromechanical switch SM is used to bypass the module when it is not energized. With SM open, switch S1 controls insertion of the series reactance. With S1 closed, a minimal level of reactance, corresponding to the STT leakage reactance, is inserted in the line. With S1 open, the STT magnetizing inductance, tuned to the desired value by setting the air-gap, is inserted into the line. At a system level, as the current in a particular line exceeds a predetermined value, increasing numbers of DSR modules are switched in, gradually increasing line impedance and diverting current to under-utilized lines. As the overall control objective is to keep lines from thermal overload, the control strategy is seen to be very simple. A control algorithm for DSR module operation is defined in (2.3).

$$Linj = Lf \frac{(I - I0)}{(Ithermal - I0)} \tag{2.3}$$

where,

L inj is the injected line inductance;

Lf is the final value of inductance with all the DSR modules on the line active;

Io is the triggering value of current for a module;

I thermal is the thermal limit beyond which there is no injection. Different modules on a line have predetermined switching levels (based on line current) that collectively provide a line inductance that increases as the line current increases above a defined threshold. Pre selected lines that are likely to see overload conditions at certain times of the day or under defined contingency conditions can be modified with DSR modules to automatically handle the congestion when it occurs, and to minimally impact the system under "normal" operating conditions. Deployment of DSR modules on a power line can thus help to realize the concept of a "Current Limiting Conductor." Control of DSR modules, when implemented on multiple lines, has to ascertain that no oscillations or interactions occur.

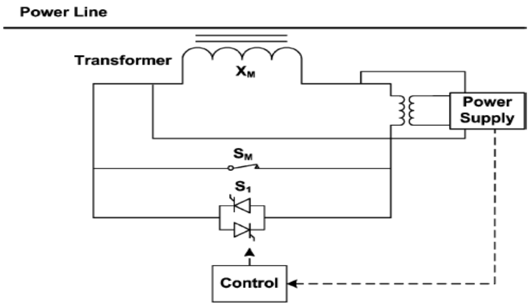


Fig.3. Circuit schematic of DSR.

C. *Distributed Static Series Compensator:*

DSSC modules consist of a small rated (10 KVA) single phase inverter and a single turn transformer (STT), along with associated controls, power supply circuits and built-in communications capability. As in the case of the DSR, the module consists of two parts that can be physically clamped around a transmission conductor. The transformer and mechanical parts of the module form a complete magnetic circuit only after the module is clamped around the conductor. The weight and size of the DSSC module is low allowing the unit to be suspended mechanically from the power line. A circuit schematic of DSSC module is shown in Fig.4. shows the STT with a normally closed switch SM consisting of a normally closed electromechanical switch and a thyristor pair that maintains the unit in bypass mode until the inverter is activated. The dc control power supply transformer is excited by the current that flows in the STT secondary winding. A simple single-switch pre-regulator is used to control the dc voltage of the control power supply. At approximately 100 A of line current, the dc power supply can initiate a turn-on of the module. As the switch SM is turned off, the inverter dc bus is charged up and inverter operation is initiated. The inverter can now inject a quadrature voltage into the ac line to simulate a positive or negative reactance. dc bus voltage regulation is maintained using power balance through a small "in-phase" voltage component, in a manner similar to active filter control [8]. The command of how much quadrature voltage is to be injected can be derived autonomously, or can be communicated from the system operator. The overall system control function is achieved by the use of multiple modules operating in a coordinated manner using communications and smart controls.

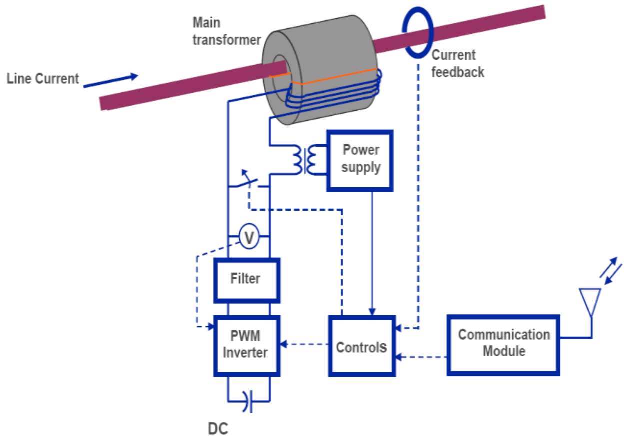
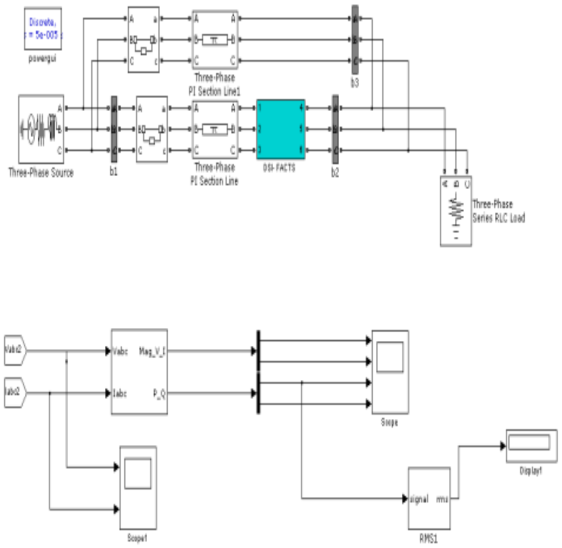


Fig.4. Circuit schematic of DSSC [9].

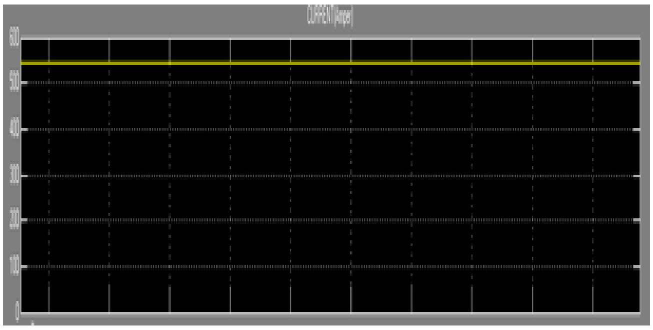
IV. SIMULINK AND RESULT

the simulink done for 132KV ,50HZ,120MVA, 525A, 0.445Ω/km Two Transmission line supply the load 240MW, assume the load is pure resistive to see the effect of change the reactance of transmission line by 0.034 Ω/km to the power transfer of that transmission line for three models as shown below.

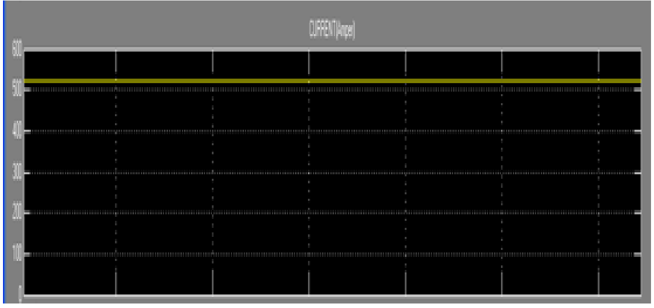
A. *DSI circuit model:*



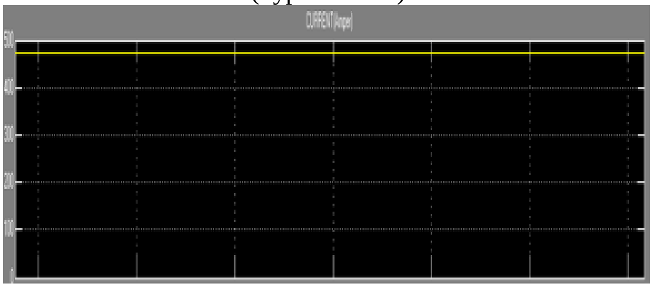
Fig(5.1)circuit diagram of simulation for DSI model



(a) current value with DSI circuit at capacitance (c) connected at secondary side.

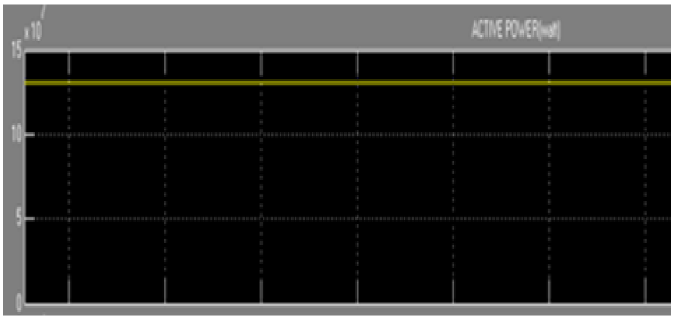


(b) current value without DSI effect (bypass mode)

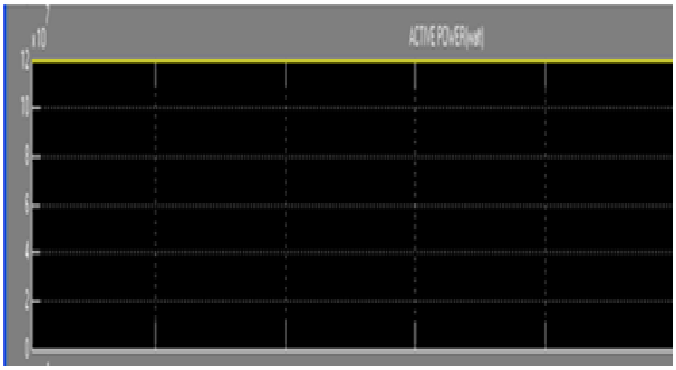


(c) current value with DSI circuit at inductance (L) connected at secondary side.

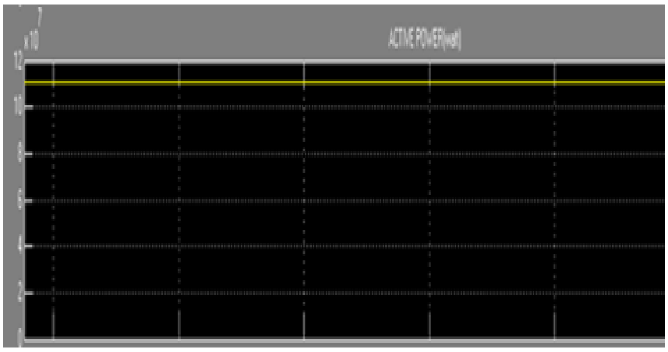
Fig (5.1.A) the value of current result from Simulink DSI model.



(a) Active power with DSI circuit at capacitance (C) connected at secondary side



(b) Active power value without DSI effect (bypass mode)



(c) Active power with DSI circuit at inductance (L) connected at secondary side

Fig (5.1.B) the value of power result from Simulink DSI model.

the fig(5.1.B) shows the power is decrease when used the inductor at secondary side of STT and depend to value of inductance and here we see the power increase from (120to 111)MVA. and it is increase when used the capacitor at secondary side of STT and depend to value of capacitance and it is appear the power increase from (120to 130)MVA.

B- DSR circuit model:

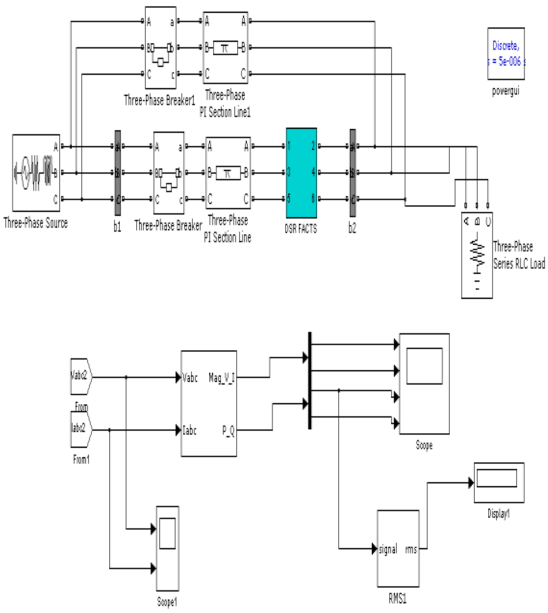
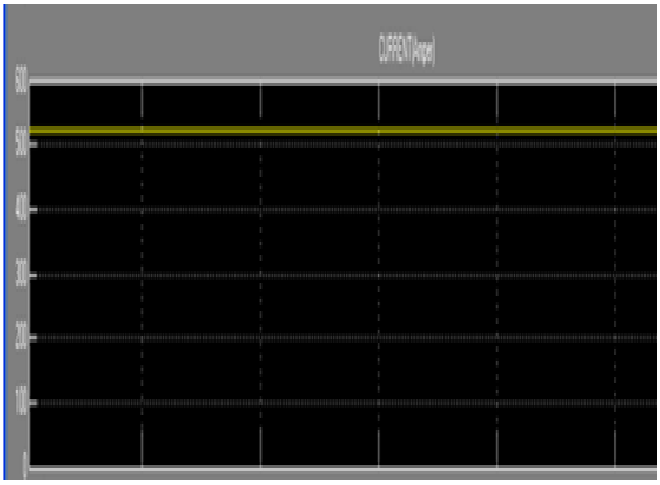
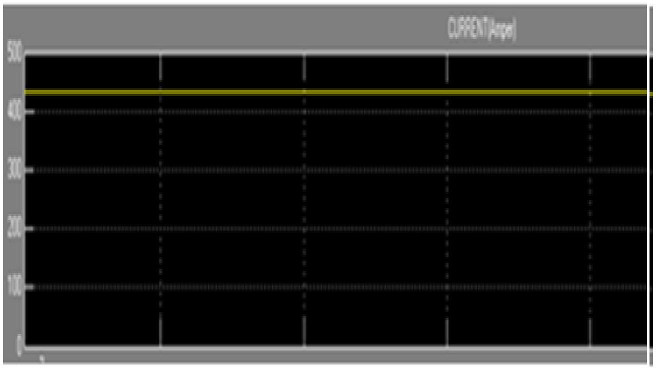


Fig (5.2)circuit diagram of simulation for DSR model

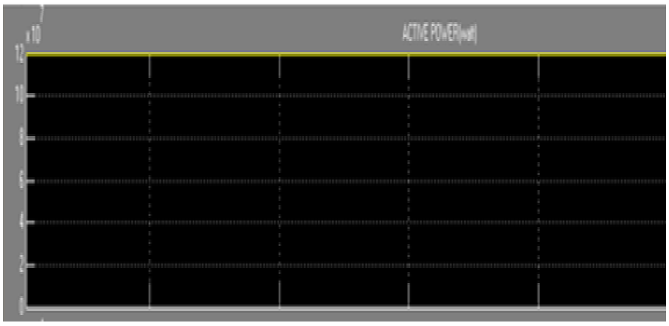


(a) current value without DSR effect (bypass mode)

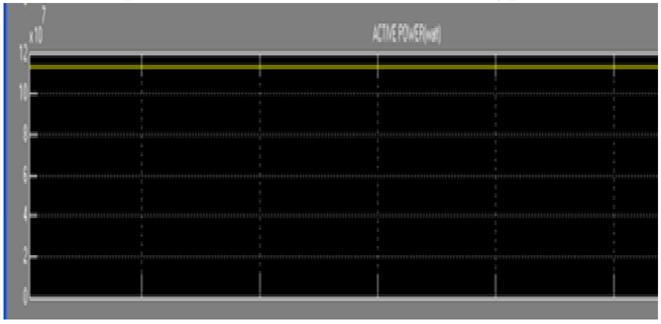


(b) Current value with DSR effect.

Fig (5.2.A) the value of current result from Simulink DSR model.



(a) Active power value without DSR effect (bypass mode)



(b) Active power value with DSR effect

Fig (5.2.B) the value of power result from Simulink DSR model.

the fig(5.2.B) shows the active power is decrease when we use DSR model and depend to reactance of STT transformer and here it is appear that value is decrease from(120 to 113.5)MVA.

C- DSSC circuit model

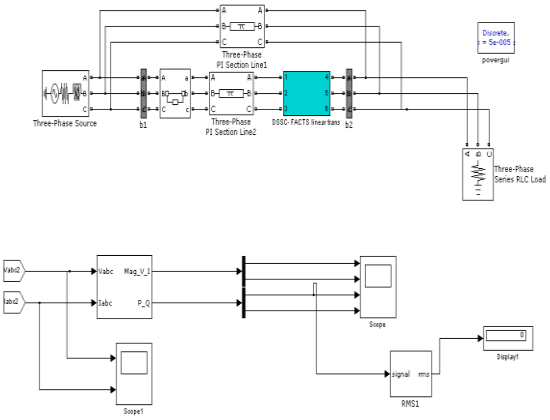
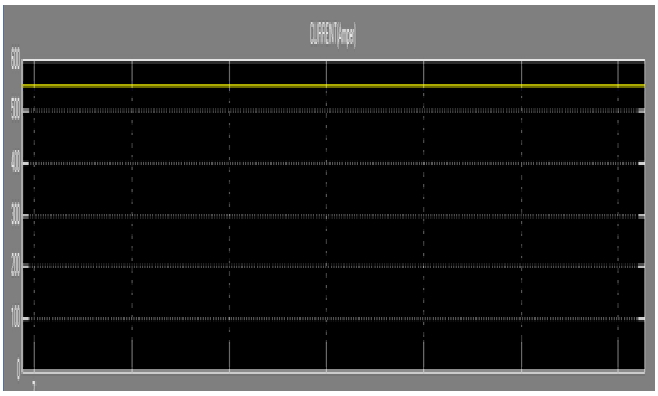
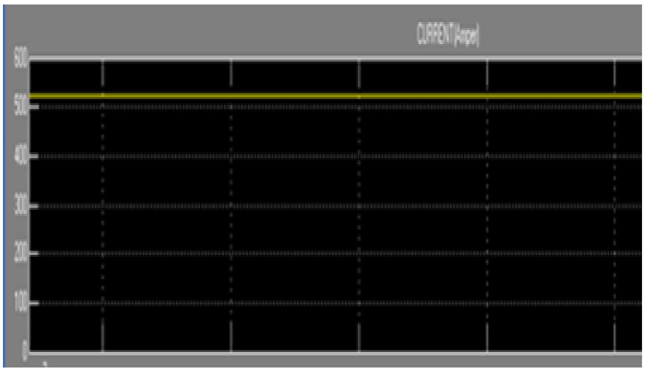


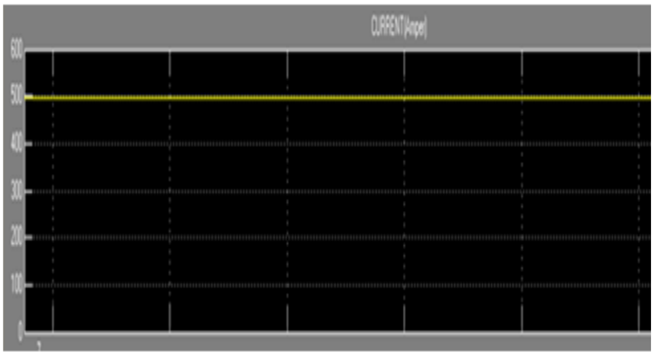
Fig. (5.3) circuit diagram of simulation of DSSC model



(a) current value for DSSC circuit at led power factor injection

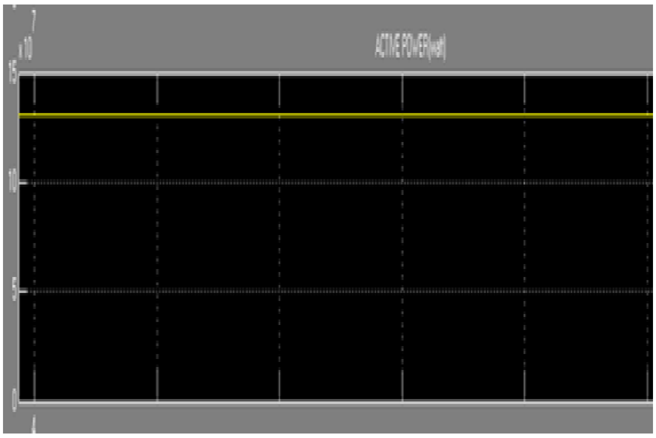


(b) Current value without DSSC effect (bypass mode)

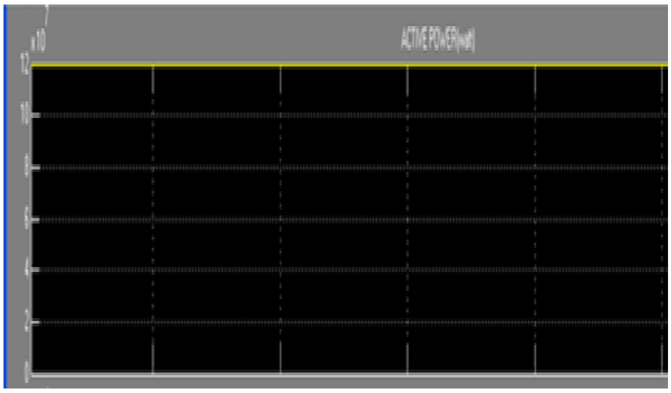


(c) current value for DSSC circuit at lag power factor injection

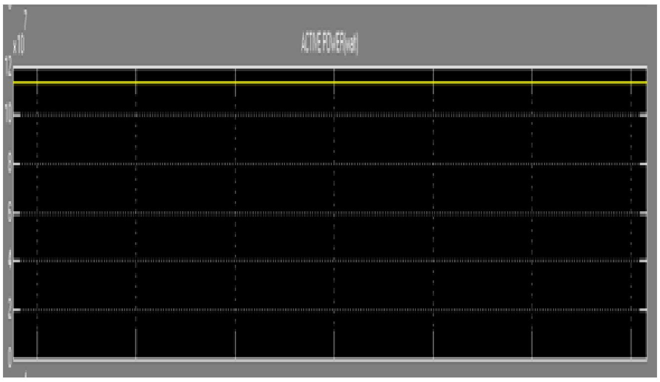
Fig (5.3.A) the value of current result from Simulink of DSSC model.



(a) Active power value for DSSC circuit at led power factor injection



(b) Active power value without DSSC effect (bypass mode)



(c) Active power value for DSSC circuit at lag power factor injection.

Fig (5.3.B) the value of power result from Simulink DSSC model.

the fig(5.3.B) shows the power is decrease when injected voltage and current at lag power factor and it is depend to the value of injected and the value of power is decrease from(120to 112)MVA and the power is increase when injected voltage and current at lead power factor and it is depend to the value of injected and the value of power is increase from(120 to 130)MVA.

V. CONCLUSION

The D-FACTS devices can operate with or without communications and use small-rated low-cost power devices. D-FACTS sustain the operation of the system even during contingency conditions, improving the reliability of the overall network. Under fault conditions, the units can instantly revert back to their bypassed mode, allowing protective relaying to operate without change if so desired, This paper presents a distributed approach for realizing active power flow control on existing power lines through the use of a new class of distributed FACTS or D-FACTS devices. The distributed implementation seems to overcome some of the most significant issues that have limited a wider deployment of series FACTS devices.

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REFERENCES

[1] Deepak Divan and Harjeet Johal "Distributed FACTS-A New Concept for Realizing Grid Power Flow Control", IEEE transactions on power electronics, vol. 22, no. 6, November 2007.

[2] N. Hingorani, "Flexible ac transmission" , *IEEE Spectrum*, vol. 30, no. 4, pp. 40–45, Apr. 1993.

[3] L. Gyugyi, C. D. Schauder, and K. K. Sen, "Static series compensator A solid-state approach to the series compensation of transmission lines". *IEEE Trans. Power Del.*, vol. 12, no. 1, pp. 406–407, Jan. 1997.

[4] S. Bhattacharya, B. Fardanesh, B. Shperling, and S.Zelingher, "Convertible static compensator: Voltage source converter based facts application in the new york 345 KV transmission system", *Int. Power Electron Conf. Records*, pp. 2286–2294, Apr. 2005.

[5] constants for 132KV&400KV overhead line for Iraq network .

[6] D. Divan, W. Brumsickle, R. Schneider, B. Kranz, R. Gascoigne, D. Bradshaw, M. Ingram, and I. Grant, "A distributed static series compensator system for realizing active power flow control on existing power lines" , in *IEEE PSCE Conf. Records*, Oct. 2004.

[7] H. Johal and D. M. Divan, "Current limiting conductors: A distributed approach for increasing system capacity and reliability", in *Proc.* Transmission Distribution Conf. Exposition 2005 IEEE PES, New Orleans, LA.

[8] P.-T. Cheng, S. Bhattacharya, and D. Divan, "Operations of the dominant harmonic active filter (DHAF) under realistic utility conditions" , *IEEE Trans. Ind. Appl.*, vol. 37, no. 4, pp. 1037–1044, Jul. 2001.

[9] Prof Deepak Divan Georgia Institute of Technology Atlanta, "Distributed Intelligent Power Networks – A New Concept for Improving T&D System Utilization and Performance " . GA 30332

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at 2009 He went to French to take training in relays and circuit breaker in Areva company, at 2011 He got scholarship to complete his study to get master in India in Sam Higginbottom Institute of Agriculture ,Technology &Sciences/Electrical &Electronic Engineering Department, under supervision .

Dr. Jyoti Shrivastava has done her graduation in Electrical Engineering and her post graduation in Design of Heavy Electrical Equipments. At present she is serving as an Senior Assistant Professor in Electrical Engineering department at college of Engineering and Technology, SHIATS, Allahabad, India. She has several international and National papers to her credit. Her field of interest and research are Power system control and operation and condition monitoring of heavy electrical equipments. Her research aims to increase T&D system capacity and enhancing system reliability.