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Editorial

Dear members,
Assalam-o-Alaikum,

This time again this journal is containing a Variety of Papers/ Articles on different issue. Two of the Papers/Articles are on the Restructuring of Power Sector in Pakistan. A very interesting Paper on Torque Optimization of switched reluctance motor, is received from Australia. A paper on Renewable Energy is also presented by researchers from University of Faisalabad.

As WAPDA is planning to get benefited from the application of FACTS Devices, a paper on application of SVC and STATCOM is also presented to elaborate the effect of such FACTS Devices on the Power System.

Any how we hope that this time again these papers and articles will help you in enhancing your knowledge. We are also looking forward to receive your comments on our journal.

Thanking you.

The Editor

"Restructuring Of Power Sector"

Paper to be read by
Muhammad Qasim Khan,
Member Power

1. Having entered the 37th year of my service in Wapda's Power Wing starting 1974 and to have witnessed one 'big bang' transition from an area board to a so called corporatized company while I was posted at Peshawar as an Xen, gives me the real 'feel of it all' from within and ever since, I have covertly nursed a subjective opinion. I am thankful to IEEEP to give me the opportunity to spill it out today to this august audience possibly for the first time in a formal manner.

2. With the permission of the Chair, I would like to take this audience on a journey backwards to the year 1988. I was Xen Haripur then and a commotion had just started in the corridors of WAPDA House at Lahore in only a few offices with a handful of officers dilating upon the strategic plan for restructuring of Wapda in the wake of financial and energy crisis that Wapda was then going through on the basis of a study concluded by the International Resources Group aided by USAID primarily meant for privatization of Pakistan Power Sector.

3. Here now, I feel the dire need to take the audience further back to the year 1947, when Pakistan achieved independence, it had then only 3 hydel power stations. Power supplies in major towns were owned and operated by private entrepreneurs. In the decade after independence demand rose very rapidly. Wapda was created in 1958 to implement Indus Basin treaty and to supply the power and water needs of the country.

4. Rapid growth continued in the 1960's. During 2nd 5 year plan (1960-65), hydel capacity rose from 67 MW to 267 MW, while installed thermal capacity rose from 39 MW to 560 MW. Power generation capacity continued to rise during 3rd 5 year plan (1965-70), although serious blackouts occurred because of delays in building large scale hydel and thermal facilities and because of bottle necks in the distribution system.

5. Seasonal variation effect reliability of hydel generation with fluctuation of 30 100% of installed hydel capacity required the hydel facilities to be backed up by thermal power.

6. Fourth plan (1970-75) was designed to eliminate deficiencies in energy planning and capacity. It sought to sustain economic growth to meet industry needs and to strengthen social services and to improve rural areas economy through rural electrification.

7. Major controversy occurred during 4th 5 year plan whether development funds be balanced between building generating capacity or improving transmission and distribution system to reduce losses. Being a stated objective, this imbalance could not get reduced because funds from donor agencies were easier to obtain for new generation projects.

8. The secession of Bangladesh in 1971 and economic dislocation from OPEC oil prices increases in 1973-74 rendered the 4th plan obsolete.

9. Wapda policy makers persued additional generation capacity as opposed to improving the T&D system, because of the greater ease with which financing from international donors could be obtained for showpiece generation projects. Over half the finances for generation projects came from foreign sources compared to 30% for transmission and less than 10 percent for distribution.

10. The last two years have been difficult ones for Pakistan. The Persian Gulf crisis led to dramatic oil price increases, supply shortages, plummeting workers remittances, repatriation of Pakistan workers from the Gulf and a loss of export market to Kuwait and Iraq.

11. This is when in 1991, the Prime Minister directed the Chairman Wapda to privatize the Pakistan power system. In moving to privatize the PPS, the GoP had 3 principal objectives :-
    - Enhance capital formation for the Pakistan Power Sector outside the GoP budget and sovereign guarantees.
    - Improve the efficiency of the PPS through competition, accountability, managerial autonomy and profit incentive, and
    - Rationalize prices and social subsidies, while maintaining certain socially desirable policies such as rural electrification and low income life line rates.

12. Under this plan, the ultimate structure of PPS was to be as follows :-
    - A no of private generation companies operating under free market competition .
    - A Govt owned corporatized entity responsible

for owning and operating multipurpose hydel facilities.

- A national transmission and dispatch company.
- Private, regulated distribution companies.
- An autonomous national regulatory authority to oversee a reorganized Wapda and the fore started companies.
- Market arrangements allowing final consumers, at least large industrial users to purchase power directly from generators or power merchants.

13. As we all know that meanwhile some priorities of the Govt kept changing, but ultimately in 1998, PEPCO came into existence where Nepra had already started in 1997. Was it a coincidence or was it intended that the deployment of army jawans in the flanks and brigadiers as CEO's of dist. Companies coincided with the onset of this strategic plan in 1999. Like many decisions that are taken in goodwill turn out wrong when practiced, this experimentation too was visibly counter productive to the success of the restructuring plan as envisaged by the international resource group, as it brought along different dimensions to the main objectives of the strategic plan. Seemingly, it lost its way before even having started.

14. The question is was the plan designed faultily or was there an error in its implementation. One thing is true which even a novice would be able to conclude that having entered the 4th and the last phase of the plan more on paper than on ground, the system is still far from yielding the desired results.

15. Here I would like to apprise the audience about the perception of the entire workforce of the would-be companies as this would be essential to lead me to reach the conclusion of my subjective opinion.

16. While all this planning was happening 1988 to 1998 the entire spread out / workforce/human resource was in a grip of uncertainty and fear as almost every one was thinking only in terms of W111FM (what is in it for me). Sincerity of purpose was amiss as is culturally the case in the public sector as a whole. They were ill informed and infact not taken on board at any time during the progress of this switch over/change.

17. They were and are operating as a whole in the prevalent culture of political influences and strong labour unions, the major factor of the negative links that do not let the most efficient ones to deliver half efficiently in their respective jobs and domains.

18. There is a saying that the change that begins from within is the one that lasts and then succeeds. This change actually was forced on a very broad base from the top with diverse dynamics not willingly accepted even by those people at the helm of the affairs, who were trying to give it a doable shape for implementation.

19. Therefore in my subjective thinking, it had all the ingredients not to succeed as expected.

20. Those who had the stearing in their hands and those who were being driven, continued to drive the new car on the same roads just like before and the road too had developed new pot holes, turns and abrasions, and their skies had changed and the way to destination had taken extended mileage.

21. Wapda in the meanwhile remained calm clear and steady as before infact steadier after unloading the distribution wing from its shoulder and folds. The character with regards to decision making remained unchanged with its three members converging on unanimous resolutions. Central Contract Cell and the Central Design office contributing richly in facilitating the system to work in harmony.

22. A Anyways, Power Sector Reforms have covered a lot of ground down the timeline, there was no respite and it is yet to come off its age and deliver on much cherished objectives foreseen in the Strategic Plan. We are at this critical make or break juncture and its high time for taking an objective view of the entire situation engulfing the Power Sector and to take bitter decisions to salvage the sector for the good of other sectors and welfare and prosperity of the people of Pakistan.

23. Succinctly, the options based on the ground realities may be as under:-

(i) Rolling back the entire Reform process to 1998 scenario, moving towards unified WAPDA.

(ii) Moving forward in the direction of reforms for a privatized competitive Power Sector to its logical end in line with the Strategic Plan.

(iii) Capitalizing on the present Corporate Power Sector, improving on its governance and putting in place a committed and professional management for turn around operations of companies.

24. For the time constraints, the analysis and merits of the first two options are put off for detailed discussions to another occasion. However, shortly I am of the view that it is not advisable to go back to square one where efficiencies and financial constraints and political interference were the compulsions for embarking on the Power Sector Reforms. For the complete competitive private regime, it is a far cry and marred by many extraneous factors where problematic Law & Order situation, dwindling commitment of the leadership has shaken the confidence of the investors.

leadership has shaken the confidence of the investors. For this reason, the entities like GENCO-1 (Jamshoro Power Generation Company) and FESCO (Faisalabad Electric Supply Company) are yet on the privatization list, despite being identified in the Strategic Plan and lot of serious efforts made in this direction have been without any dividends. This situation is further compounded by little success in this direction from the experience of power utilities around the World and contain hardly any good promises, the KESC fiasco is an eye opener for unheeded privatization. Exception is a Northern Delhi Power Company a much smaller company compared to our DISCOs but whatever little success it has achieved, can be attributed to the BOD with full stakes and strong/professional management group TATA that has closely been monitoring the operations of the company, may be for its own repute.

25. It will, however, be unfair on our part if good practices of the Northern Delhi Power Company are not copied, of course after fine tuning for suiting to our socio-economic conditions. This is precisely the option three as pointed out earlier i.e. to strengthen the Corporate Power Sector.

26. The Power Sector Reforms could be implemented substantively on the corporatization segment of the Reforms, other stages like commercialization and preparing the entities for privatization are yet under early stages of restructuring. The corporatization has helped us in identifying the profit-centers / cost-centers, we can see what cash flows are coming from where. It has helped us in understanding of the tariff dynamics charging the customers on the cost of service rationalizing the social considerations and in working the role of GoP for assistance on the lifeline and other socially desirable segments of the society.

27 If it was intended to read this paper in this forum as a cosmetic lip service, then I think I have said enough to close my paper right here, but if I have to be aptly objective then the matter does not end here infact it really starts here.

The companies should continue to stay in the public sector privatization is never the answer nor recommended. Thermal generation (GENCOs) and NTDC should return to Wapda.

We have to be mindful of the fact that all countries infact even all cities within the same country have their own cultural environment. Its no use riding allien band wagons. This is like looking for our problems here while they are lying there far away.

Therefore, with solemn pledge first that we have total sincerity of purpose and the honesty and the guts to deliver then taking the following measures head on are the bare minimum requirement and the only way to come out of the power crisis in shortest possible time, provided that these steps have the full backing of the GoP, and the same is implemented through special ordinance :-

(a) Improving the Governance

i) Absolute minimization infact almost bringing to a halt any political influence or interference in all its manifestations in all the companies.

ii) Coming up with the ideas of revamping the BODs of Power Sector Corporate Entities, from the Directors nominated by Professional Bodies like IEEEP, ICAP, Chamber of Trade and Commerce, Academcia, Power Utility Professionals, Third Party Labour Representation, so as to provide a sense of ownership to the Directors in the BOD.

iii) Filtering through only the most honest and competent Power Utility Professional as Chief Executive with his team of Chief Engineers in all the companies. Appropriately enhancing the package of salaries of all officers and staff of the companies or replacing it with Performance-based Compensation System and then reposing full trust in the CEO's for fast hire and fire actions.

(b) **Introduction of IT Solution**

Removing two categories of the working force in the companies namely the 'meter readers' and the 'bill distributors' by replacing them with technology and installing Technology Based Asset Management System.

(c) **Demand and Supply Side Management of Electricity**

Inculcation of Energy Management and Conservation Culture amongst the masses giving them awareness and ownership on the Energy Potential in the country.

(d) **Improving the performance of GENCOs**

Running GENCOs like IPPs, where CEO and Operational Management are fully empowered and autonomous in its operation.

(e) **Integrated Human Resource Development**

i) A comprehensive programme on HR development is required for continuously improving and harnessing the potential of Professionals.

ii) Raising the motivation level of employees by reposing trust and confidence in them and r in the making them partner in the successful operations. Any extraneous checks in the above scenario would be counter productive and therefore it has to be eliminated.

(f) **Improving the energy and consumer mix**

i) Replace oil with indigenous resource based like gas and coal (even if imported) for thermal generation and to take on hydel generation to turn to generation mix of 70-30 in favour of hydel generation as a base load. What can be a matter of greater injustice, that a country with largest coal reservoir and larges hydel potential is forced to waste the precious foreign exchange on the purchase of fuel.

ii) The consumer mix to be rationalized for enhancing the revenue generation in the DISCOs

(g) **Defusing / subduing the activities of the labour unions**.

28 Now, having come this far, the first and the last, time-framed mandate for CEO and his team has to be as follows:

i) To start with, as charity begins from home. All CEO's to purge total theft of electricity in the premises of all Wapda officers and staff with actions not less than dismissal of all those directly/ indirectly involved in the theft of energy within a given time frame.

ii) Then, the above exercise to be extended to all government officers/premises provincial and federal with similar action.

iii) Legislators with same action without fear or discrimination.

iv) All industrial, commercial and private consumers.

v) Firm disconnections of all govt/private defaulters till only when the arrears are paid without let off.

29 The after effects of above activities will ensure following results:

Gross reduction in Line losses.

Huge recovery of dead and running arrears.

Less load, thus less demand on the system and hence no load shedding.

Lesser passed on tariff to consumers.

Lesser interruptions of electricity.

Minimal circular debt.

Happier consumers.

Better governance by the government.

Improved economy.

And last but yet not the least

A Prosperous Pakistan.

*****

Some Aspects Regarding Short Circuit Currents In Power Systems

By
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Abstract

In this paper some aspects of short circuit currents, their adverse effects as well as methods of calculations are elucidated.

Calculations regarding short circuit currents are essentially required for sizing electrical equipment. However, these are considered as very complex calculations by a vast majority of power engineers. In the recent past some charts and tables have been devised in the U.S.A which have greatly simplified the whole matter and any electrical engineer can easily ascertain the short circuit currents. Such simplified new methods are included in this paper.

The above mentioned charts and tables are applicable to American power system, hence these cannot be directly used for our power system. However, WAPDA or NTDC can easily prepare similar charts for the use of our electrical engineers.

Introduction

Many years back, during early eighties, the author happened to work in Electricity Department Libya and was shocked to see that many electricians of the Electricity Department who worked at a particular remote town had got their hands burnt and suffered severe wounds while switching on some L.V circuit breakers (C.B.) which had got exploded. On investigation it was found that the C.B. had less short circuit withstand capacity whereas at the location of application, fault level was higher. Initially the L.V. Circuit was being fed from a 25kVA, 13.8/0.4kV Transformer which had 5% impedance and hence the maximum fault current, which the C.B. had to break was merely 722 Amps while its interrupting rating was 5000 Amps. Later, the transformer was replaced by a 200kVA transformer which had 5% impedance, however, the L.V. C.B. was not changed. The maximum fault current became 5776 Amps and so the C.B. got exploded while closing on a short circuit.

Whereas overload currents occur at a rather modest level, the short-circuit or fault current can be many hundred times larger than the normal operating current. A high level fault may be 50,000 amperes (or larger). If not cut off within a matter of a few cycles (say 5 or 8 cycles), damage and destruction can become rampant-there can be severe insulation damage, melting of conductors, vaporization of metal, ionization of gases, arcing, and fires. Simultaneously, high level short-circuit currents can develop huge magnetic-field stresses. The magnetic forces between bus bars and other conductors can be many hundreds of Newtons per linear meter and even heavy bracing many not be adequate to keep them from being warped or distorted beyond repair.

It must be borne in mind that huge short circuit current, if not mitigated within a few cycles, can destroy transformers, cables, busbars, C.Ts, P.Ts and every other equipment which is not designed to withstand the fault current which is prevailing at the point of application.

Protective Devices And Their Interrupting Rating

A protective device (i.e a circuit breaker or a fuse) must be able to withstand the destructive energy of short-circuit currents. If a fault current exceeds a level beyond the capability of the protective device, the device may actually burst, causing additional damage. Thus it is important, when applying a fuse or circuit breaker, to use one which can sustain the largest potential short-circuit currents. The rating which defines the capacity of a protective device to maintain its integrity when disconnecting a fault current is termed its "interrupting rating". The interrupting rating of most branch-circuit, molded case circuit breakers typically used in residential service entrance panels is 5000 or 10,000 amperes. Larger, more expensive L.V. circuit breakers may have interrupting ratings of 14,000 amperes or higher. In contrast, most modern, current-limiting fuses have an interrupting rating of 200,000 or 300,000 amperes and are commonly used to protect the lower rated circuit breakers.

The National Electrical Code of U.S.A Section 110-9, requires equipment (i.e. C.B etc.) intended to break current at fault levels to have an interrupting rating sufficient for the current that must be interrupted.

Faults On Power Systems

Various faults (for instance, single phase to ground fault, phase to phase fault and three phase type faults) in a power system occur because of insulation failure in a plant and there are various reasons for the same (for instance due to aging, the insulation around the winding of a generator may become defective). Such faults cause heavy current, called short circuit current, to flow in the system.

The sources of fault power originate in all generators and some other plant (such as a synchronous motor or an induction motor) present in the system. It should be borne in mind that in this regard the contribution of small induction motors, being quite insignificant, can be safely neglected. However, synchronous motors as well as large induction motors where considerable flywheel effect is available act as generator in the event of reduced frequency. Where induction machines such as these are connected and they are of size as to have an effect and these are connected to a point close to that for which short circuit values are being calculated, these should be included in the calculation. However, synchronous motors are always taken into account.

Some Fundamental Aspects

The subject of short circuit studies is considered a very intricated one and this is the reason why many power engineers, other than Protection Engineers, have a dim idea about it. In this regard many wrong ideas are prevailing. For instance one perception is that short circuit studies cannot be carried out without a computer software. This idea is not wholly true. For instance in a 132 kV grid station the fault current calculation on the 11 kV bus usually does not need any computer software as this is quite simple one. This aspect is further explained in the following paragraphs.

WAPDA has prepared a Power Study Report, which is regularly revised and updated. In the said report 3-phase symmetrical short circuit fault currents, at all the existing grid stations, on 550kV, 220kV and 132kV buses are indicated. WAPDA has ascertained these fault currents with the help of some famous computer softwares. It should be noted that due to various reasons, it is not always possible to represent any power system in its entirety including 33kV and 11kV substations. Even on a 220kV substation the fault levels at 33kV and 11kV bus-bars may not be available from the network analysis reports. Let us assume that the fault level at 220kV bus-bar has been found, for a particular gridstation, as 3300MVA and at 132kV bus-bars as 1755 MVA. It is required to ascertain the fault level on the 33kV busbars when a transformer of 40 MVA, 132/33kV and having a percentage impedance of 10% is installed on that substation. Refer to Figure 1 where the system is shown.

Assume a base of 100 MVA. First the system reactance up to 132kV busbars may be determined by the formula:

$$X_S = \frac{Base\ MVA \times 100}{Fault\ MVA\ (at\ 132kV)} = \frac{100 \times 100}{1755} = 5.7\ percent \qquad (i)$$

The corresponding percentage reactance (it is assumed that resistance is negligible) of 40 MVA transformer at 100 MVA base will be = $\frac{100 \times 10}{40} = 25\ percent$ (ii)

The system can now be represented as shown in Figure 1(B). Therefore the total reactance = Addition of (i) and (ii) = 30.7 percent

Now using the formula, Base MVA x 100/percentage reactance, the fault level on the 33kV busbar will be = 100 x 100 / 30.7 = 325.73 MVA

As recommended by Ref. 1, the circuit breaker's rating should be about 25% more, so 325.73 x 1.25= 407.1625 MVA.

Hence on the 33kV busbar, circuit breakers having 500 MVA interrupting rating can be safely installed.

(Note: These days interrupting rating of circuit breakers is represented in the form of kA. However, having obtained MVA rating of a circuit breaker, the same can be easily converted in the kA form.)

When a symmetrical 3-phase short circuit is applied to the armature of a synchronous generator having damper windings on the rotor, the initial short circuit current is limited by the sub-transient reactance (almost equal to the armature leakage reactance) and in a very short time, of the order of a few cycles, this current decreases to the transient value limited by the transient reactance (slightly higher than the sub-transient reactance) and then it settles down to the steady state short circuit value limited by synchronous reactance. For short circuit studies of generators, the sub-transient values of reactance are considered.

Briefly, it can be said that there are two types of faults; one is three phase symmetrical short circuit fault and the other type is unsymmetrical fault. The latter include single phase to ground faults, and phase to phase faults etc. So far as three phase symmetrical short circuit faults are concerned, these can be calculated very easily and in many cases, these are the faults which produce largest fault current. In Annexure No. 1, a calculation example is included to elucidate as to how to calculate these.

According to an author (Ref. 1), for solidly grounded three phase system (for instance the one which is used in the Auxiliary power system in a hydro power station or in WAPDA's distribution system etc.), if 3-phase symmetrical short circuit current is say 1000 Amps then line to line, and line to ground fault current will not exceed 870 Amps and 1000 Amps respectively. There are some places (for example inside a Power Station or inside a High Voltage Substation), where the line to ground fault current may exceed the 3-phase symmetrical short circuit current. According to Ref. 1, in the above mentioned case, the maximum possible value of single phase to ground fault value can be 1250 Amps. However, in general, in WAPDA's distribution system or in a factory or a commercial building the line to ground fault current will not exceed the three phase symmetrical short circuit current.

It may be added that, in general, for a large system comprising many power stations and grid stations, single phase to ground fault current etc. has to be determined with the help of a reliable computer software because longhand calculation is a cumbersome method of calculation. Even for a small problem, a computer program may be required to complete it in a short time. For a medium or large network, short circuit study is always carried out with the help of a computer software.

How N.E.C (U.S.A) Can Help Us

National Electrical Code of U.S.A, Ref. 2, is being used in the U.S.A for well over 100 years. Being very helpful, practical and easy to use, it is also being followed in many other countries. For instance it is also being used in the Eastern Region of Saudi Arabia where ARAMCO is working for the past 80 years. After every three years the code is revised and up-dated. The latest edition was published in the year 2008. Further, there is some American technical literature (and Tables, refer to Table No. 1 and Table No. 2) which can help us towards quickly and easily solving the problems of short circuit currents. In Annexure-2, a problem is given and it is solved with the help of some charts which are also attached. It amply demonstrates that it is so easy to solve the problem of short circuit current with the help of these charts.

There is a word of caution. Since the voltages as well as conductor sizes in the U.S.A are quite different from those which are used in Pakistan, the above said Tables and Charts cannot be directly applied. We have to get similar Tables and Charts prepared for our conditions. Some of the Tables can be prepared by WAPDA /NTDC while some other Tables indicating "C" values for the various cables can be got prepared from local cable manufacturers such as A.E.G or Pakistan cables etc.

Conclusion

For the proper selection of protective devices as well as other electrical equipment (for example circuit breaker, fuse, cables, bus bars, C.Ts etc.), it is essential that the value of fault current at the point of application of the above said Protective Device and other equipment should be known and it is determined with the help of some calculations. If circuit breakers or fuses of inadequate interrupting capacities are installed, these may explode and can bring in disasters for the operator as well as buildings.

Also cables and other equipment having inadequate short circuit withstand rating can catch fire.

In this paper some charts/ tables (refer to Table No. 1 and Table No. 2) which are much used in the U.S.A (and in some other countries such as Saudi Arabia) are added. It is demonstrated that with the help of these charts, it is quite easy to ascertain the fault currents.

It is vehemently recommended that WAPDA and NTDC should get these charts prepared with the help of their own design engineers as well as some Pakistani cable manufacturers like A.E.G or Pakistan Cables since "C" values can be conveniently provided by the above said manufacturers.

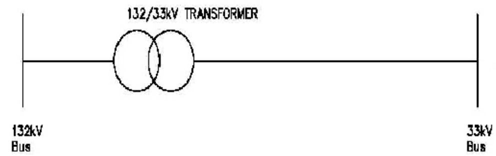


FIGURE 1 (A)

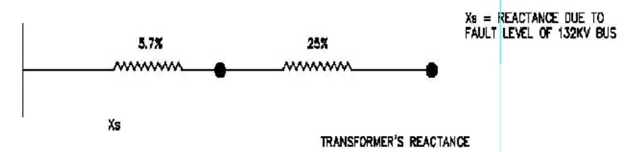


FIGURE 1 (B)

FIGURE 1: SCHEME SHOWING 132kV AND 33kV BUSBARS AS WELL AS REACTANCE DIAGRAM.

References

1. "Electrical Wiring Commercial, 10th Edition" by R.C. Mullin and R.L. Smith, ISBN 0-7668-0179-9 published by DELMAR Publishers, U.S.A.
2. "National Electrical Code, 2008", published by National Fire Protection Association, U.S.A.
3. "American Electricians Handbook", 15th Edition, Page 2.45, published by Mcgraw Hill Books company, New York, U.S.A.

Table No. 1: Three-phase Symmetrical Short-Circuit Currents at Various Distances from a 300 kVA 13.2/0.208kV oil-filled Transformer
Percentage Impedance of Transformer = 2%

3 Phase Secondary Voltage	Wire-Size (Copper)																							
	DIST. (FT.)	#14	#12	#10	#8	#6	#4	#1	0	00	000	2-000	0000	250 Kcmil	2-250 Kcmil	3-300 Kcmil	350 Kcmil	2-350 Kcmil	3-350 Kcmil	3-400 Kcmil	500 Kcmil	2-500 Kcmil	750 Kcmil	4-750 kcmil
208 VOLTS	0	42090	42090	42090	42090	42090	42090	42090	42090	42090	42090	42090	42090	42090	42090	42090	42090	42090	42090	42090	42090	42090	42090	42090
	5	6910	10290	14730	19970	25240	29840	34690	35770	36640	37340	39610	37930	38270	40100	40870	38840	40410	40960	41030	39300	40650	39650	41460
	10	3640	5610	8460	12350	17090	22230	29030	30760	32210	33410	37340	34420	35030	38270	39710	36040	38840	39870	40010	36850	39300	37480	40840
	25	1500	2360	3670	5650	8430	12150	18930	21170	23240	25000	31710	26750	27780	33590	36560	29550	34780	36930	37230	31020	35730	32190	39090
	50	760	1200	1890	2950	4530	6810	11740	13670	15610	17510	25090	19320	20520	27780	32250	22660	29550	32850	33340	24520	31020	26050	36480
	100	380	600	960	1510	2350	3610	6610	7920	9320	10810	17510	12320	13380	20520	26010	15400	22660	26850	27530	17250	24520	18860	32190
	200	190	300	480	760	1190	1860	3510	4280	5140	6090	10810	7110	7860	13380	18660	9360	15400	19590	20370	10820	17250	12150	26050
	500	80	120	190	310	480	760	1460	1800	2180	2630	4990	3130	3500	6510	10030	4290	7820	10770	11400	5100	9120	5870	16570
	1000	40	60	100	150	240	380	740	910	1110	1350	2630	1620	1820	3500	5650	2250	4290	6140	6560	2710	5100	3160	10310
	5000	10	10	20	30	50	80	150	180	230	280	550	330	380	740	1260	470	930	1380	1490	570	1130	670	2560

Source: Reference 1

Table No. 2: C Values Pertaining to cables for Calculating Available Short -Circuit Currents

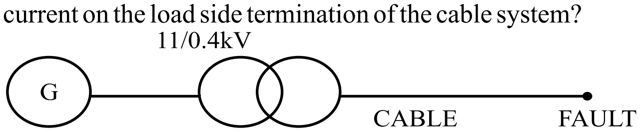
AWG or kcmil	Copper Conductors Three Single Conductors						Copper Conductors Three Single Conductors					
	Steel Conduit			Nonmagnetic Conduit			Steel Conduit			Nonmagnetic Conduit		
	600V	5KV	15KV	600V	5KV	15KV	600V	5KV	15KV	600V	5KV	15KV
14	389	-	-	389	-	-	389	-	-	389	-	-
12	617	-	-	617	-	-	617	-	-	617	-	-
10	981	-	-	981	-	-	981	-	-	981	-	-
8	1557	1551	1557	1556	1555	1558	1559	1557	1559	1559	1558	1559
6	2425	2406	2389	2430	2417	2406	2431	2424	2414	2433	2428	2420
4	4779	3750	3695	3825	3789	3752	3830	3811	3778	3837	3823	3798
3	4760	4760	4760	4802	4802	4802	4760	4790	4760	4802	4802	4802
2	5906	5736	5574	6044	5926	5809	5989	5929	5827	6087	6022	5957
1	7292	7029	6758	7493	7306	7108	7454	7364	7188	7579	7507	7364
1/0	8924	8543	7973	9317	9033	8590	9209	9086	8707	9472	9372	9052
2/0	10755	10061	9389	11423	10877	10318	11244	11045	10500	11703	11528	11052
3/0	12843	11804	11021	13923	13048	12360	13656	13333	12613	14410	14118	13461
4/0	15082	13605	12542	16673	15351	14347	16391	15890	14813	17482	17019	16012
250	16483	14924	13643	18593	17120	15865	18310	17850	16465	19779	19352	18001
300	18176	16292	14768	20867	18975	17408	20617	20051	18318	22524	21938	20163
350	19529	17385	15678	22736	20526	18672	22646	21914	19821	24904	24126	21982
400	20565	18235	16365	24296	21786	19731	24253	23371	21042	26915	26044	23517
500	22185	19172	17492	26706	23277	21329	26980	25449	23125	30028	28712	25916
600	22965	20567	17962	28033	25203	22097	28752	27974	24896	32236	31258	27766
750	24136	21386	18888	28303	25430	22690	31050	30024	26932	32404	31338	28303
1000	25278	22539	19923	31409	28083	24887	33864	32688	29320	37197	35748	31959

Source: Reference 1

Annexure 1

Calculation Example

A three-phase 11kV, 1000 kVA alternator having 24% sub-transient reactance is connected to a three-phase 1000kVa 11/0.4kV transformer having 10% reactance. 1000 mm^2, 3 x 1 phase cables are connected between the transformer and the load; the reactance of the cable system is say 1.0 ohms. What will be the 3-phase symmetrical fault current on the load side termination of the cable system?



Solution:

Base MVA = 1000kVA = 1

- Percentage sub-transient reactance of generator = 24 ---------------------(i)
- Percentage reactance of transformer = 10 ---------------------(ii)
- Percentage reactance of cable system by formula:

$$\frac{Base\ MVA \quad 100 \quad (\text{Reactance } in\ \ ohms)}{(Voltage\ \ in\ \ kV)^2}$$

$$\frac{1 \quad 100 \quad 1}{(0.4)^2} = 625 = \text{------------------- (iii)}$$

- Total reactance upto the fault = 24 + 10 + 625 = 659 percent
- 3-phase symmetrical fault level on the load-side of the cable system= $\dfrac{Base\ MVA \quad 100}{\%\ impedance} = \dfrac{1 \quad 100}{659}\ MVA$

or 3-phase symmetrical Fault current = $\dfrac{1 \quad 100 \quad 1000}{659 \quad 0.4 \quad 1.732}$ = 219 Amperes

Note:-

If the transformer is connected to the utility bus, instead of the generator, then fault level of the utility bus (which is usually given by the utility) is converted to percent reactance. After that the same procedure as above is used to ascertain fault level on the load side of the cable.

Annexure 2

Numerical Example:

By using the attached chart (Table No. 1), find three-phase symmetrical short circuit current at the load side of 3 core x 50 mm^2 L.V. cable (which is being fed from a three phase 13.2/0.208kV 300kVA Dy11 transformer and having 2% impedance) while the length of the cable is 10 feet.

Solution:

Step - 1: Refer to Annexure - 4 where AWG sizes and corresponding metric sizes are given. AWG size # 1/0 is nearly equal to 50 mm^2.

Step - 2: Since the 3-phase voltage on the secondary side of the transformer is 208 volts (line-to-line) so enter Table No. 1 where distance "10 feet" is appearing. Enter the vertical column under cable size # 1/0. Three-phase short circuit current is 30760 Ampere.

Notes:

(1) This table i.e. Table No. 1 is only applicable for a 3-phase 300kVA, delta-star transformer and having 2% impedance. Further the transformer's 3-phase primary and 3-phase secondary voltages are 13.2kV and 208 volts (line to line).

For any other transformer having a different kVA and a different % impedance, another table will be required.

(2) For cable lengths which are not indicated in the above said Table (for instance 24 feet), interpolation should be carried out to ascertain the short circuit amperes.

Annexure 3

Finding Short Circuit Currents By Using Charts

In the U.S.A, cable manufacturers have produced charts similar to Table No. 2 attached herewith. In these table, "C" values for different sizes of the cables (for example AWG # 1 or 2 etc.) are indicated.

According to this method, suppose 3-phase symmetrical short circuit current at the secondary side of a 13.2/0.208kV 3-phase 300kVA transformer (having 2% impedance) is 42090 Amps (this is read from Table No. 1). We want to ascertain 3-phase symmetrical short circuit current on a PVC cable outgoing from the transformer. Cable size is AWG # 1, and it is three conductor cable (600 volts grade) contained in Non-magnetic conduit. The length of the 3-phase cable is 50 feet. "C" value from the attached Table No. 2 is 7579 Ampere.

Calculation is done as below:

Step 1: Fault current at the power supply side of the cable = I = 42090 Amps

Step 2: For 3-phase symmetrical short circuit current

"F" factor = $\dfrac{1.73 \quad L \quad I}{N \quad C \quad E_{L\ L}} = \dfrac{1.73 \quad 50 \quad 42090}{1 \quad 7579 \quad 208} = 2.3095$

L = Length of the circuit to the fault, in feet

I = The available fault current in amps at the beginning of the circuit

C = constant from Table No 2

E_{L-L} = Volts, Line to Line

N = No of conductors in parallel. (If only one 3-phase circuit is outgoing, then N = 1).

Step 3: Factor M2 = 1/(1+f) = 0.3022

Step 4: Fault current at the load side of the cable = M2 x I = 0.3022x42090

= 12719.59 say 12720.0 Amperes

Note:

Formula for finding "f" factor in the case of single phase cables will be:

$$\text{"f" factor} = \frac{2 \quad L \quad I}{N \quad C \quad E_{L\ L}}$$

Here L, I, N, C etc have the same meaning as in the case of 3-phase explained above.

Size AWG	Wire Diameter (inch)	Cross-sectional Area		Remarks
		Circular mils	mm^2	
4/0	0.4600	211,600	107.22	(1) For conversion, 1 circular mil = $\frac{0.5067}{1000}$ mm^2 is used
3/0	0.4096	167,800	85.02	
2/0	0.3648	133,100	67.44	
1/0	0.3249	105,500	53.45	
1	0.2893	83,690	42.41	(2) For standard copper conductor, circular mils as well as mm^2 will be different from those which are shown in this table.
2	0.2576	66,370	33.63	
3	0.2294	52,630	26.67	
4	0.2043	41,740	21.15	
5	0.1819	33,100	16.77	
6	0.1620	26,250	13.30	
7	0.1443	20,820	10.55	
8	0.1285	16,510	8.37	
9	0.1144	13,090	6.63	
10	0.1019	10,380	5.26	
11	0.0808	6,530	3.31	

Torque Optimisation of Switched Reluctance Motor using Finite Element Method

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Abstract

This paper presents simulation results for three phase, 6/4 poles and four phase, 8/6 poles switched reluctance motor (SRM). The main focus of this paper is to investigate the developed torque optimization for switched reluctance (SR) motors as a function of pole arc/pole pitch ratio for the stator and the rotor. This investigation is achieved through the simulation using Finite Element Method (FEM).

Index Terms-- Switched Reluctance Motor; Simulation; Design Optimisation; Finite Element Method.

I. Introduction

The switched reluctance motor is a new entrant in domestic appliance applications. Many electrical machine researchers are investigating the dynamic behaviour of switched reluctance motor (SRM) by monitoring the dynamic response (torque and speed), monitoring and minimising the torque ripple, building different types of controllers to reduce the cost, to increase the general performance of SRM like high reliability and high practicability [1-8]. The researchers are now focusing on switched reluctance motors and drives with only one or two phase windings so that applications for the technology are being created at low cost, high volume markets such as domestic appliances, heating ventilation and air conditioning and automotive auxiliaries [9,10].

The switched reluctance motor's (SRM) principle of operation has been known for more than a century, under general name of the doubly salient variable reluctance motor. However, an intensive research on SRM began about thirty years ago, mainly due to the progress in power electronics and microprocessors [1]. Its principal advantages are simple and robust construction, possibility to work at very high rotational speeds, high mechanical torque at low speeds, and simple power electronics drives [6,7].

Anunugam et a1 [11] have compared analytical method and FEM method for calculating average torque at different pole arc and pole pitch combinations for a fixed value of air gap length. Also their work lacks a detailed analysis on the optimum geometry of SR motor for different combination of design parameters. The sensitivity study is performed by comparing the average torque developed for different stator as well as rotor pole-arc/pole-pitch ratios. The ratio combination that produces the greatest value of average torque is then chosen. The sensitivity analysis of SR motor geometry is carried out for stator- and rotor pole-arc/pole-pitch ratio, and radial air gap length as motor design variables by a few researchers [11-18]. The optimum design variables are chosen which results in maximum average torque developed by the motor. The results of a two-dimensional finite element analysis conducted on an 8/6 switched reluctance motor for studying the effects of air-gap non-uniformity on the overall developed torque profiles [14].

Finite element method (FEM) is very powerful tool for obtaining the numerical solution of a wide range of engineering problems. The basic concept is that a body or structure may be divided into smaller elements of finite dimensions called "Finite Elements". The original body or structure is then considered as an assemblage of these elements connected at a finite number of joints called "Nodes" or "Nodal Points". The equations of equilibrium for the entire structure or body are then obtained by combining the equilibrium equation of each element such that the continuity is ensured at each node. FEM has also been used to study the electromagnetic designs of SRMs [17-19].

II. Optimized Design (4-Phase)

The finite element method (FEM) can be used to solve any problem that can be formulated as a field problem. It can produce accurate and reliable results when designing electromagnetic devices [18]. It is a valuable design tool, provided it is used correctly and can save money, materials and time. This paper presents the torque optimization of a SRM by using finite-element analysis. The effects of different rotor and stator shapes and sizes on the performance were investigated. Finite element method was used to simulate each shape of SRM, while various stator/rotor shapes are analysed keeping the same ampere-turns for various SRM shapes.

Fig. 1a shows a 4 phase, 8/6 poles SRM, while the cross section SR motor is shown in Fig. 1b, This motor is the reference 4 phase, SR motor, with á = stator pole arc â^s/rotor pole arc â^r equal to 1. Fig. 1c shows the torque developed in the reference SR motor versus displacement angles, while varying the mmf (ampere- turns), ATs from 200 to 4000. As expected, it is found that the torque is increasing with increasing ampere - turns. Fig. 1d shows the torque developed in the reference (or base) SR motor versus different mmfs. For each mmf, the rotor position displacement is changed from aligned to unaligned positions. The lowest developed torque is obtained at rotor positions equal to (0°) and (30°). As both torque values are too low (nearly zero), it appears as a single curve as shown in Fig 1d, while at the intermediate positions, the developed torque is higher than the torque values in aligned and unaligned positions.

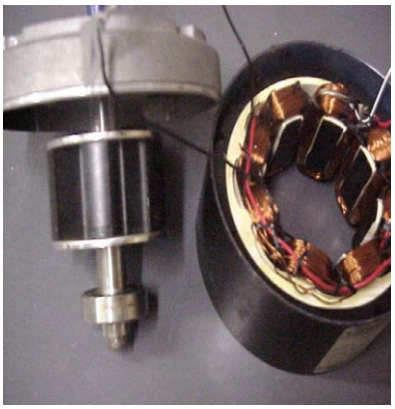


Fig.1a: 4 phase, 8/6 SRM

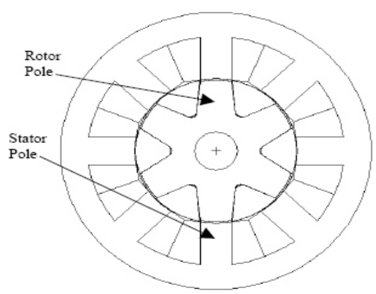


Fig. 1b: Cross section for 4 phase, 8/6 poles Reference (or base) SR motor

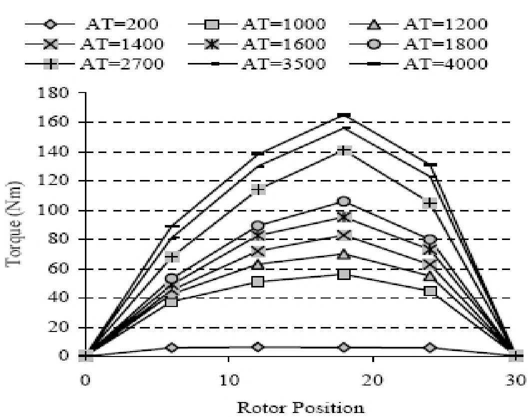


Fig.1c: Torque versus rotor position at different MMFs

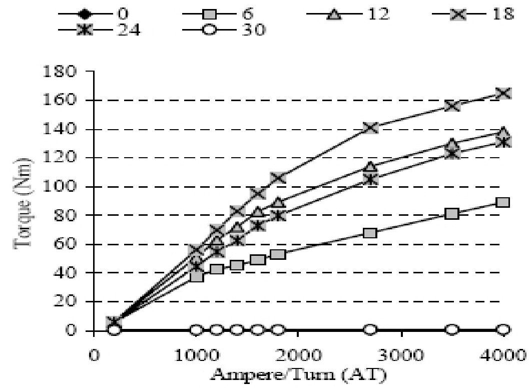


Fig. 1d: Torque versus MMFs at different rotor positions.

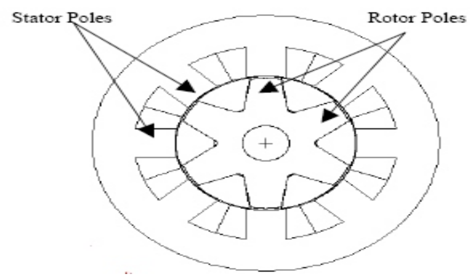


Fig. 2a: Optimised SR motor configuration

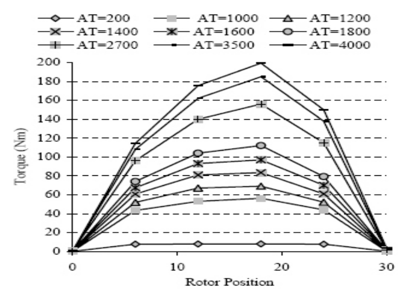


Fig. 2b: Torque versus rotor position at different MMFs

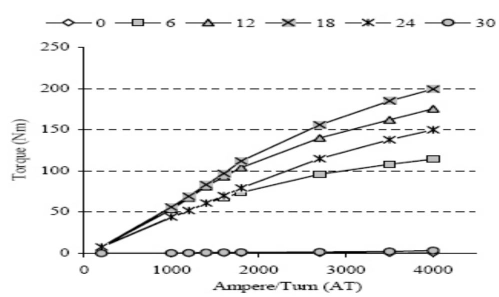


Fig. 2c: Torque versus MMFs at different rotor angles

The investigation has been performed with various configurations as follows:

- Changing the shape and size of the rotor and stator.

• Dimensional variations for stator and rotor poles.

Torque optimization has been achieved by dimensional variation on the stator, the rotor poles. After investigating the results of the highest developed torque for the stator, and the rotor poles, a new SRM optimized design is obtained. The stator pole arc/pole pitch ratio (ã) for the optimized SRM is 0.5; the rotor pole arc/pole pitch ratio ã for optimized SRM is 0.38.

Fig. 2a shows optimised switched reluctance motor after dimensional variations are applied to the rotor, stator and yoke of the reference switched reluctance motor, with â = (stator pole arc $â^s$ / rotor pole arc $â^r$) = 0.76. Fig. 2b shows the torque developed in the optimised SR motor versus displacement angles while varying the mmf from 200 to 4000 ATs. It is obvious that the developed torque, obtained from optimised SR motor, is higher than the developed torque values obtained from the reference or base SR motor. Fig. 2c shows the torque developed in the optimised SR motor versus different values of mmfs. For each mmf, the rotor position displacement is changed from aligned to unaligned positions. The lowest developed torque is obtained at aligned and unaligned positions, while in the intermediate positions, the developed torque is higher than the torque in aligned and unaligned positions. Figure 3 shows the average torque variation as a function of pole arc /pole pitch ratio (ã). It can be seen that an optimum ã exists for particular size and configuration of SRM.

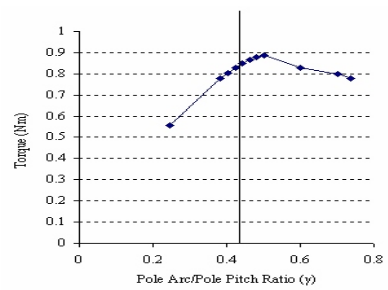
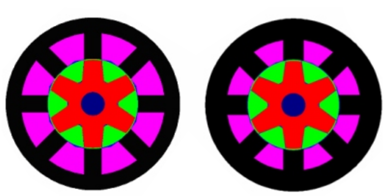


Fig. 3. Torque versus pole arc/pole pitch ratio (ã)

Since the torque optimization is performed by dimensional variation of stator, rotor poles of 3 phase, 8/6 poles base SRM. Figure 4 shows cross sections for SRM, the base design and the optimized design for 4 phase, 8/6 poles SRM.



a) b)
Figure 4: Configuration of SRM (8/6 poles)
a) Base design b) Optimized design

Figure 5 shows the average torque developed from reference or base design and optimized design SRM. The developed torque for optimized SRM is slightly higher than the developed torque of base SRM when the mmf varies from 200 to 1000 ATs. The developed torque of the optimized SRM increases rapidly compared with the developed torque of base SRM between 1000 to 4000 ATs.

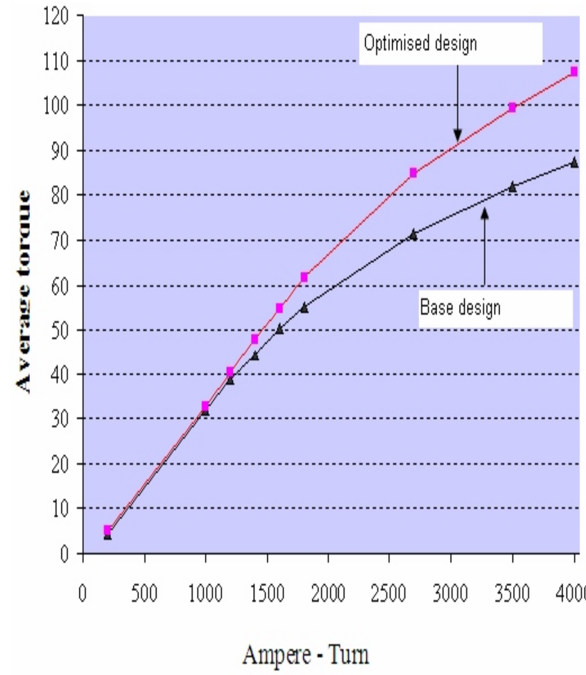
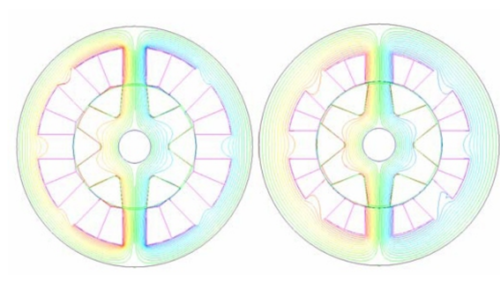


Figure 5: Average torque versus ampere-turns for 4 phase, 8/6 poles base and optimised srm.

Figures 6a and 6b show the flux distribution through the yoke, stator pole, air-gap, and rotor for 4 phase, 8/6 poles base and optimized SRMs respectively.



a) b)
Figure 6: Flux distribution in 4 phase, 8/6 pole SRM
a) Base design; b) Optimized design

Figure 7 shows the flux linkage versus current variation for 4 phase base SRM from 0.2 to 10 amperes, while the rotor moves from unaligned to aligned positions in step of 4.2°.

IV. Conclusions

The incremental torque percentage for the optimized design 3 Phase, 6/4 Poles phase SRM is 11.5% greater than the developed torque of the equivalent base design 6/4 poles SRM. The incremental torque percentage of the optimized design for 4 phase, 8/6 poles SRM is 12.9% greater than the developed torque of the base design for 4 phase, 8/6 poles SRM. It is shown that finite element method can be usefully employed to predict optimum configurations. Similarly yoke geometry can be optimised.

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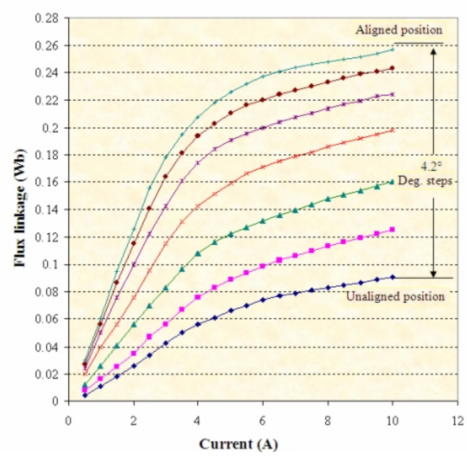
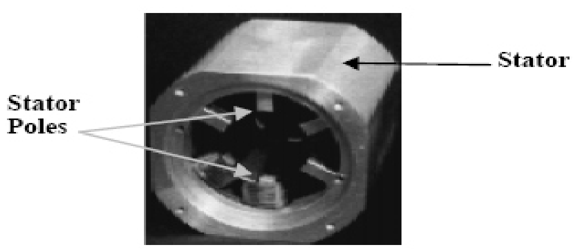
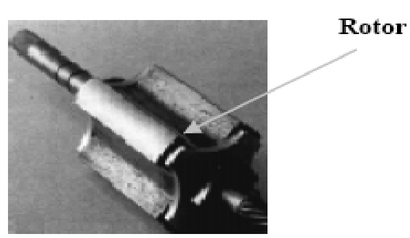


Figure 7: Flux linkage versus current for 4 phase, 8/6 poles base srm.

III. Optimized Design (3 Phase Srm)



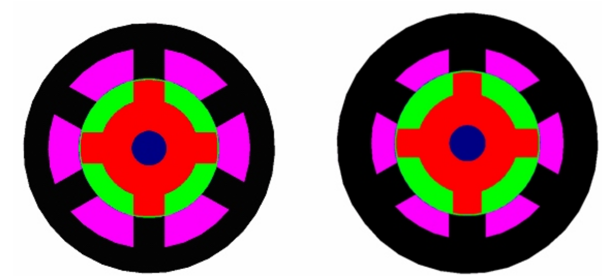
(a)



(b)

Fig. 8. a) Stator and b) rotor for 3 phase SRM

Torque optimization has been attempted for another configuration of SRM (3 phase, 6/4 poles), as shown in figure 8. A new optimized design is obtained after parametric variations and applying finite element analysis. Figure 9 shows the base design and the optimized design for 3 phase, 6/4 poles SRM. The stator pole arc/pole pitch ratio (ã) for the optimized SRM is 0.5; the rotor pole arc/pole pitch ratio for optimized SRM is 0.38.



a) b)

Figure 9: 3 Phase, 6/4 Poles SRM
a) Base design b) Optimized design

Figure 10 shows the graphical results for developed torque for the 3 phase, 6/4 poles reference or base design and the optimized design. The developed torque is computed when the rotor moves from 0º to 45º. The torque developed in the optimized design is less than the torque developed in the base design when rotor rotates from 0º to 5º; the torque developed for optimized design is higher than the developed torque for the base design when the rotor rotates from 5º to 45 º.

Figures 11a and 11b show the flux distribution through the stator pole, air-gap, and rotor for 3 phase, 6/4 poles base and optimized designs of SRMs.

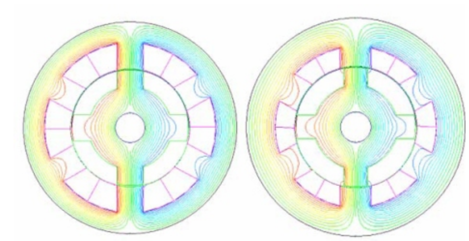


Figure 10: Flux distribution in 6/4 Poles,SRM
a) Base design b) Optimised design

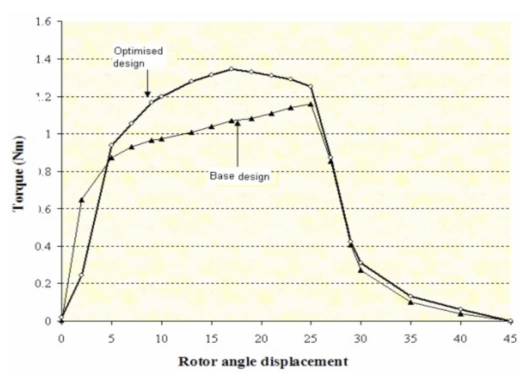


Figure 11: Torque versus è for Base SRM and Optimised SRM.

Optimized Fuel Injection System for Industrial Burners

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Electrical Engineering Department UET, Lahore Pakistan)

Abstract

Automation engineers worldwide have been striving to develop systems, which are capable of meeting the ever-increasing performance demands and emission constraints. There have been numerous breakthroughs in the process industry. Fuel Optimization is one of these breakthroughs. It is not a new concept for engineering sciences because there has always been a scarcity of natural resources. Optimization refers to the utilization of available resources in the most efficient manner. This paper proposes a solution to the industrial sector for minimizing the per annum fuel consumption for industrial burners through; the implementation of specialized PID controller structure , the concept of Multi-Feedback closed loop for the injection of fuel and the development of HMI. This proposal is under the umbrella of Burner Management Systems (BMS), specifically FM 7605 Programmable Logical Controller Based Burner Management Systems which is an internationally followed Standard for Burner Based Applications. It comprises of two folds;

1. *Implementation of Intelligent closed loop Multi-Feedback control concept for fuel injection using Modular PID Controller Structure.*
2. *Human-Machine Interface (HMI) development using WinCC5.0* which makes it an open system for panel configuration. This feature crafts it as an industrial automation application.

OPTIFI-System features following elements.

- Programmable Logic Controller
  CPU-314 IFM
- Windows Control Center 5.0
- Modular PID controller Structure
- PID self Tuning Mechanism

1. Introduction

Before going into the details of how I developed & implemented the concept of multi feedback close loop system with Modular PID controller, it is mandatory to give a full picture of what the basic problem in fuel consumption is and how I have minimized those problems. According to the case study I had executed, I found out that, in most of the process industries of Pakistan, the fuel injection is Un-Optimized.

1.1 Un-Optimized System

It can be observed in Fig. 1 that the over fueling region and over heating regions are wider enough to cause fuel and heat losses in a combustion process. If we explain the reason in a detail, we can observe that the temperature of a chamber, which is currently at ambient state, does not respond immediately to the new set point assigned to achieve. Rather the fuel supply is at its prescribed quantity, which is required by that state of temperature. This causes **over fueling** conditions in a system. On the other side of things, when constantly provided fuel burns out for quite some time and the desired temperature is achieved, temperature does not stop rising strictly at desired level (set point) which causes over heating condition to occur in a system.

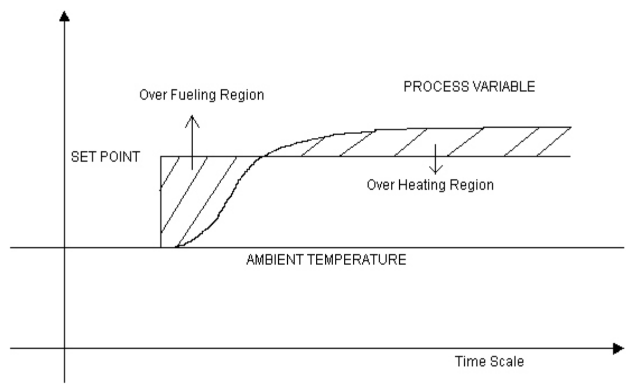

Fig: 1 Un- Optimized (Parallel) System.

1.2. Optimized System

It can be observed in Fig. 2 that the over fueling region and over heating regions become narrow enough to not to cause fuel and heat losses in a combustion process. Let's see how these losses are minimized. We can observe that the temperature of a chamber is currently at ambient state. Now if the fuel supply is provided such that a small change in temperature is desired in response and unless the controller does not sense that small change, the fuel supply is not increased. This causes no over fueling conditions to occur in a system. On the other side of things, when fuel supply is gradually increased as per required by the amount of temperature to be achieved, all supplied fuel burns out efficiently before the next desired temperature is approached and if temperature achieves its set point, further fuel is required just to maintain that temperature which does not causes over-heating condition to occur in a system.

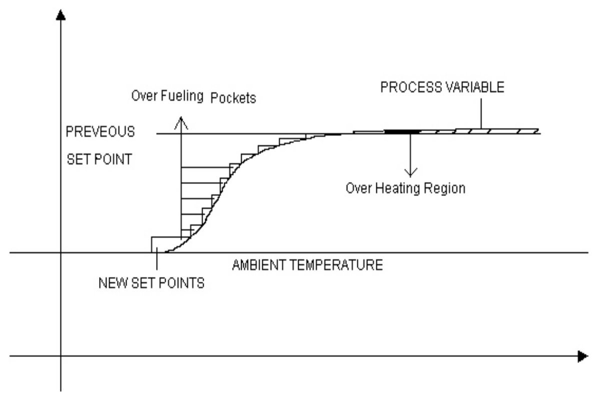

Fig 2: Optimized (Cross Limited) System.

2. Process Execution

The system include a means of monitoring the presence of flame and a reliable method and procedure for operating the associated fuel valves in a particular sequence that provides the safe ignition at start up and safe shut-down either in the event of fault or to an operator command. The procedure of lighting a burner depends, first, on checking that it's safe to light it at all. This means that the confirmation has been received that any flammable mixtures have been exhausted from the furnace by means of a purge. This pre-purge of furnace is achieved through the operation of air inlet for a defined time period so that a certain volume of air has passed through the furnace. Once the confirmation has been received that the furnace purge is complete ignition of a burner will depends on the successful operation of igniter and pilot and once the burner has been successfully lit, its operation is continuously monitored, because an extinguished flame may mean that unburned fuel is being injected into the combustion chamber. If such fuel is subsequently ignited, it may explode. Once the burner has ignited, the Burner-Management- System ensures that the safe operation continues, and if any hazard arises the system goes to an emergency shut off of the burner, and if necessary, trips the entire plant. On shut down of a burner steps are taken to ensure that any unburned fuel is cleared from the pipe work. This procedure is known as scavenging

3. Concept

3.1. Cross Limited Control

As mentioned earlier in Fig 2 that the cross-limited combustion control system is used for optimization purpose. This system addresses the features of failure protection in a very comprehensive manner. This is some how a self-diagnostics controller. In this system, individual flow controllers are provided for the fuel and air systems, respectively. It can be seen that the master demand signal is fed to each of these controllers as the desired value signal, so that the delivery of fuel and air to the furnace continually matches the load. Because fuel & airflow is measured as a part of closed loop, the system compensates for any changes in either flow that may be caused by external factors. (Fig. 3)

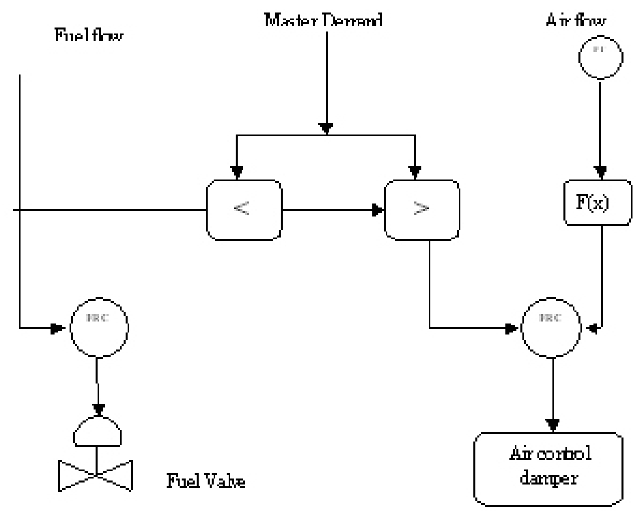

Fig: 3 Control Concept.

4. Close Loop Control Diagram

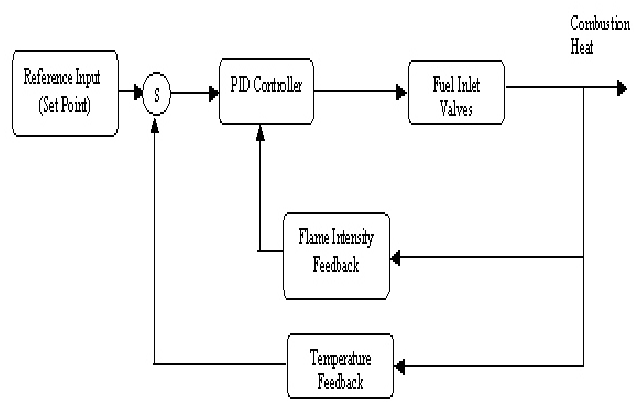

Fig: 4 Close Loop Control Diagram.

5. Chemical Validation

In case of Methane being used as fuel, it is desirable to maintain a fuel to air ration of 2:1.

5.1 Incomplete Combustion

Incomplete combustion means burning in a lack of air (less than enough). If there is not enough oxygen available for all the carbon to turn into carbon dioxide (Complete Combustion), then some or all of the carbon turns to carbon monoxide. This happens with any hydrocarbon. The gas burns with a yellow flame (unlike the blue flame seen in complete combustion). Carbon (sooty marks) may also be seen.

$$2CH_4 + 3O_2 \quad CO + 4H_2O$$

Carbon monoxide is a very poisonous gas. It cannot be seen or smelt. Faulty gas fires or boilers may produce carbon monoxide and poison the air in a room without anyone knowing.

5.2. Complete Combustion

Complete combustion means burning in an excess of air (more than enough), when all the carbon turns to carbon dioxide. The gas burns with a clear blue flame.

$$2CH_4 + 3O_2 \quad CO_2 + 4H_2O$$

The reaction is exothermic (gives out heat).

6. Human Machine Interface

I have used SIEMENS made WinCC software as HMI tool. It's the world's first HMI software system, which truly integrates your plant controller software with an automation process. WinCC is an industry- and technology-neutral system for solving visualization- and controls related tasks in production and process automation. OPTIFI-System is a single-user application (OS) in which I have implemented WinCC as an HMI tool at front end to communicate with SIMATIC S7 PLC at runtime.

In OPTIFI-System application, I have developed Mimics for individual plant operation, which includes the configuration Panel, PID Loop Analyzer, PID Diagnostics, Real time Data archiving and Alarm logging for generation of warnings and emergency conditions. There are six Mimics for control and monitoring of OPTIFI-System.

1. Configuration Panel
2. Loop Analyzer
3. PID Diagnostics
4. Plant View
5. Data Trends View
6. Parameter Archiving
7. Alarm Logger

7. Conclusion

- By precise observation of the records at the project site it has been found that the combustion efficiency has been improved by 12% through controlling the injection process electronically. Hence, the injection of industrial fuel has been optimized in order to achieve desired temperatures.
- The design is based on PLC as a central controller & windows control center (WinCC) as a front end HMI. These two utilities make it according to industrial automation concepts.
- Due to the programming interlocks, the plant is more safe and reliable & fulfills the BMS requirements.

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Hybridization Of Photovoltaic Thermal & Bio Gas Power System

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Abstract:

The energy shortage and environmental pollution is becoming an important problem in these days. Hence it is very much important to use renewable power technologies to get rid of these problems. The important renewable energy sources are Bio-Energy, Wind Energy, Hydrogen Energy, Tide Energy, Terrestrial Heat Energy, Solar Energy, Thermal Energy & so on. Pakistan is rich in all these aspects particularly in Solar and Thermal Energies. In major areas of Pakistan like in South Punjab, Sind and Baluchistan the weather condition are very friendly for these types of Renewable Energies. In these areas Solar Energy can be utilized by solar panels in conjunction with thermal panels. The Photovoltaic cells are used to convert Solar Energy directly to Electrical Energy and thermal panels can be uses to convert solar energy into heat energy and this heat energy will be used to drive some turbine to get Electrical Energy. The Solar Energy can be absorbed more efficiently by any given area of Solar Panel if these two technologies can be combined in such a way that they can work together. The first part of this paper shows that how these technologies can be combined. Furthermore it is known to all that photovoltaic/thermal panels depend entirely on weather conditions. So in order to maintain constant power a biogas generator is used in conjunction with these. Moreover in last section of paper it is proposed that the controllability of system can be further improved by using MPC controller instead of PI controller.[1]

Keywords: Renewable Energy, Distributed Power system, Biogas Generator, Modeling and Simulation.

Introduction:

The worldwide demand of electrical energies is increasing day by day. But the limited resources and environmental pollution is becoming a biggest challenge for mankind.. In this frame of reference the role of every pollution less, economically efficient energy generation system is more important and considerable. Up till now the concept was that economic power generation is only possible in large power plants and in low range power plants it was not developed. But now in these days the concept of power generation in small scale by using renewable energy resources is getting more and more acceptance. The combined working of small plants depending on both renewable and non renewable resources is called distributed power system. Hence DPS can be defined as;

"It is small set of co-operatory power plants, generating electricity with renewable and non-renewable primary energy carries, working together with the help of highly advanced power electronic systems in order to fulfill the load requirement".[2]

DPSs are majorly connected to main power grid but in some cases they can work independently in order to feed some housing societies, farms and small industrial plants etc.

Obviously the major benefit of DPS is to supply far away remote areas where main grid connections is not an easy task because of the cost of connections.

The renewable energy distributed power system contains two or more renewable power generating plants, which work together in order to boost up their advantages and in order to remove disadvantages. There are many types of DPS such as:

DPS with Photovoltaic and Thermal;

DPS with Photovoltaic and Biogas;

DPS with Thermal and Biogas;

DPS with photovoltaic/Thermal and Biogas etc.[2]

All these sources are environment friendly and they don't produce pollution. The all above mentioned sources can be classified into two types, Controlled Sources and Uncontrolled Sources [2].

The controlled sources are those sources whose output power can be controlled according to demand such as Biogas Power Plants. In these Power Plant the generated power can be controlled by controlling the amount of input fuel gas.

The uncontrolled sources are those sources whose output is not controllable. These sources depend on weather conditions. For example Photovoltaic and Thermal power plant is uncontrollable because these plants depend on sun light and which is turn depend on weather conditions.

So uncontrolled plants can be used in conjunction with controlled power plants. So by using this technique the power supply can be controlled according to the load demand. In first section of this paper the Solar Panels are Photovoltaic cells are used in conjunction with Thermal Panels. Both of these are uncontrolled plants.

So after that in second section Biogas Generator is used with these in order to improve the controllability of power.

Section I:-

Photovoltaic/Thermal Energy System:

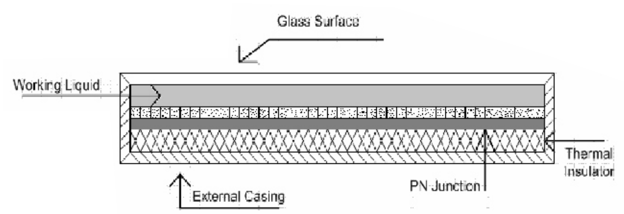


Fig 1. Construction of Combined phtovoltaic/Thermal Panel [2]

The photovoltaic cells can be used directly to convert solar energy into electrical energy. While thermal panels can be used to convert solar energy into heat energy and this energy can be in directly used to run a turbine or stuff like that to produce electrical energy. This Solar energy can be more effectively utilized by making a combined Photovoltaic/Thermal panel. In this case the overall efficiency of system will be high, over all cost will be less due to less number of controllers required and life time will be more than that of individual plants. [2]

Demonstration of System:

The power generated by solar energy can be increased if Photovoltaic and Thermal technologies are combined in such a way that they work in conjunction to produce electric and heat energies. This type of combination will be very useful for Pakistan and other Asian Countries because in this region the weather is hot and sunny. Also this combined structure offers many advantages such as cost savings, efficiency and payback period[7]. The research work aimed to improve the performance of this combined system and to insure the continuity of energy with Increasing load. The simplified diagram of this structure is shown above in fig. 1.

In this structure the entire cell is divided up into two halves. The upper half is made up of transparent plastic and it carries working liquid which will be used in a heat exchanger and after that this heat will be used to run any turbine. The lower half section is the solar panel which is used to convert solar energy directly into electrical energy. The outer boundary is the protective layer of the entire system. The solar radiations which penetrate into this system are firstly utilized to heat up the working liquid and then they are used to produce free electrons in the solar panel. The upper transparent plastic layer has a special inner coating so that rays cannot be reflected back.

A complete model of Photovoltaic/Thermal panel is shown below in figure 2. The Photovoltaic panel is used directly to charge up a battery through a charge controller and the thermal cell is used to heat up a liquid which is further used to produce stream through a heat exchanger. This system is used to run a turbine. Both parts of this systems depend solely on weather conditions so an auxiliary stream generator with some heat in put can be used in order to assure the continuity of power.[1]

The Photovoltaic panel charges battery through a charge controller which prevents over charging and deep discharging of battery.

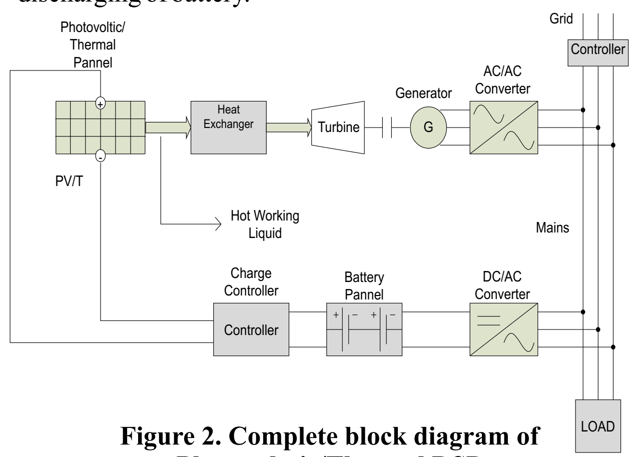


Figure 2. Complete block diagram of Photovoltaic/Thermal DSP

Simulation Studies:

The complete analysis of this system is very much difficult because of non linear nature of building blocks of this system. The energy balance for this system is very much important. This energy balance can be estimated or analyzed by calculating generating electrical power and comparing it with load demand. But load is not a linear function so it can only be estimated from past load requirement record. As simplified Matlab/Simulink model of this system with peak load of 1.5KW, rated battery voltage 48V and battery capacity of 400Ah is shown below in fig 3.

This simulation diagram consists of three major blocks, PID controller, batteries and Photovoltaic cells. The PID controller is used to control the current of DC/AC converter after accepting an error signal which is difference between reference voltage and battery actual voltage level. The Solar cell current is calculated by using solar cell V-A characteristics and an approximate radiation Vs time table. The number of series and parallel connected cells are also considered. The load current is estimated by using several past values of load current and rated load current. The solar cell current and load current corresponds to battery current from which after integrating, battery charge can be obtained. Now the charge Vs. voltage graph being stored in look up table is used to calculated battery voltage. The difference between this battery voltage and reference voltage is error signal used by controller.

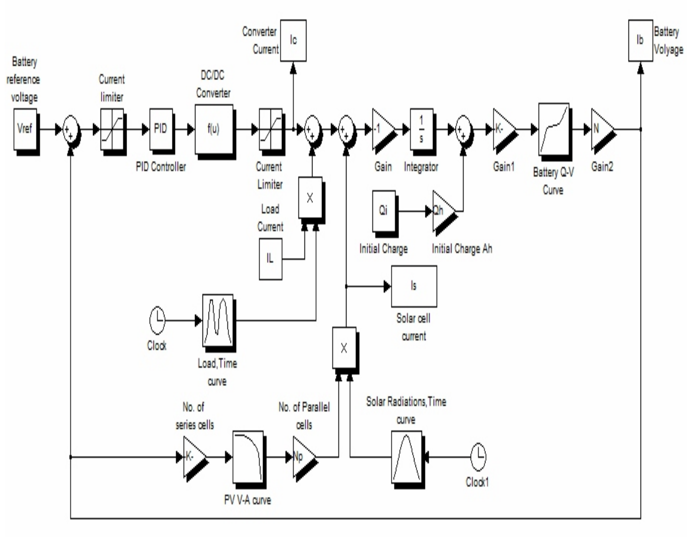


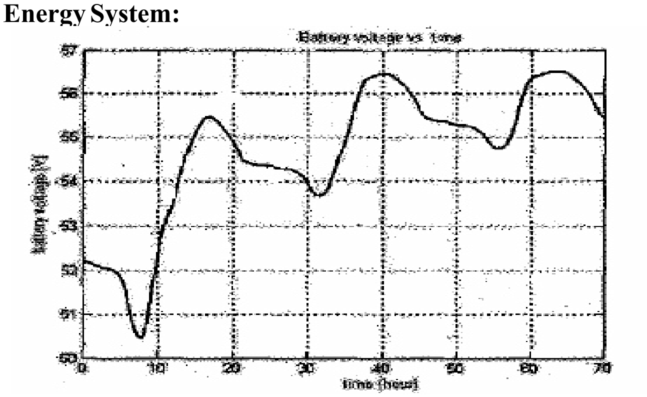
Figure 3. Matlab/Simulink model of Photovoltaic system [3]

Simulation Results:-

The simulation result of battery voltage vs. time is shown below. This simulation result is for about 70 hours, in which it clear that battery voltage increases with increasing intensity of sun light. Battery charges to it maximum value in about 38 hours. All other simulation results can be well seen by using the simulation model shown above in Matlab/Simulink. The description of entire simulation results is not possible in limited volume of this paper.

Section II:-

Combination of Photovoltaic/Thermal and Biogas Energy System:



The solar power depends on weather conditions. It is known to all that solar power changes with time and space. So DPS with Photovoltaic/Thermal power system is not suitable for continuous user needs. Biogas is generated by anaerobic degradation of organic material in the absence of air and in the presence of microorganisms [2]. The source of Biogas is waste of Industries, Agriculture and Towns etc. This Biogas is fired to drive some generator or turbines etc [2].The Biogas power generation is controlled power generation mechanism and it can be used to balance the power output from Photovoltaic/Thermal panels.

The block diagram for combined Photovoltaic/ Thermal and Biogas system is shown below.

Power Flow of System:-

The current of Photovoltaic cell is DC and is supplied to AC bus bar through a DC/AC converter to change voltage level and other electrical parameters. The power generated by thermal part of cell is supplied to the AC bus bar through AC/AC converter and the power generated by Biogas generator is also fed to AC bus bar through AC/AC converter. The direction of output power is depicted in the following figure.

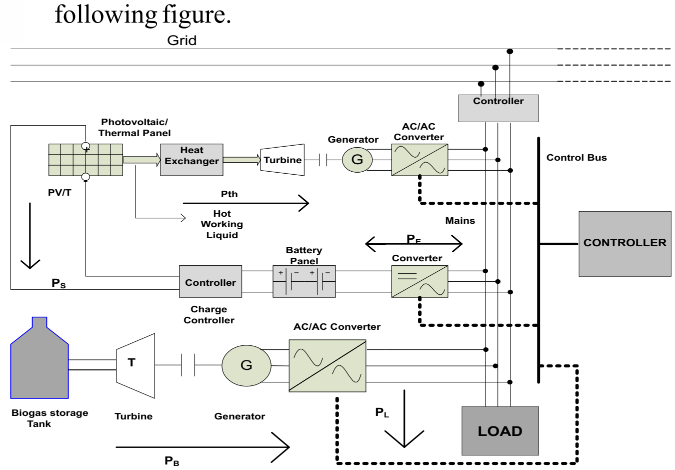


Figure 3. Complete block diagram of phtovoltaic/thermal and blogas DSP

Now there are three relations between power generated by all these sources and load.

Case I:-

$$P_S + P_{TH} > P_L + P_E$$

This $P_G > 0$ i.e; this system will supply to grid.

Case II:-

$$P_S + P_{TH} < P_L + P_E$$

The controller will control power generated by Biogas generator and will remove deficiency i.e;

And again $P_G > 0$

Case III:-

$$P_S + P_{TH} + P_B < P_L + P_E$$

Then $P_G > 0$

Hence the grid system will remove the deficiency of power.

Controller Design:-

The Photovoltaic/Thermal Biogas system is a complex system so that whole model of this system is difficult to get. In this system there are two separate controllers; One controller is the charge controller. It is a basic controller which is used to prevent battery from overcharging and deep discharge. The second controller is the major controller which compares the output power generated by Photovoltaic/Thermal panel with power requirement of load and utilized that error signal to generate command signal for Biogas power plant.

The instantaneous power generated by biogas generator is;

Pi = pVni/120

Where i is amount of gas supplied in Vats.

And Pi is instantaneous power.

The output developed torque is given below;

T = 9550Pi /n

Where is efficiency.

MPC Controller:-

The second major controller which is used to control the power generated by the Bio gas generator can be replaced by an MPC controller because of its advantages over PI controller. Model predictive control is an advanced method of process control being used in process industries such as chemical plants and oil refineries etc. [4]

MPC controller uses the model of the entire system to predict the behavior of the dependent variables (outputs) of the modeled dynamic system with respect to changes in process independent variables. The predicted outputs are then compared with the actual outputs in order to generate the error signal. This error signal is used again to generate the control signals.[7]

The experimental results show that Model Predictive Control with explicit solution of the optimization problem is applicable for drive control, since the online calculation time is in the same range as for PI controllers. The performance of the Model Predictive Controller is slightly better than PI control especially in small-signal operation even with the simple machine model. Certainly, similar or even better results can be obtained using more sophisticated PI controllers with feed-forward control or disturbance compensation, but MPC offers much more facilities. Making use of these features, it should be possible to increase the control performance even more. Hence, explicit MPC might be a promising alternative to PI control for electrical drives.[5]

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Conclusions:-

The first section of this paper suggests that Photovoltaic/Thermal panels can be used in conjunction. This system can be used in stand alone mode or UPS system can also be connected to this system. In the second section it was proposed that since Photovoltaic /Thermal systems depend entirely on weather conditions hence a Bio gas generator can be used along with these. By using this technique it was shown that constant output power according to the load demand is possible.

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Quotation

* Obscurity and competence - that is the life that is best worth living.
  Marks Twain

* It took me fifteen years to discover I had no talent for writing, but I couldn't give it up because by that time I was too famous.
  Robert Benchley

* Be not afraid of greatness: some are born great, some achieve greatness and some have greatness thrust upon them.
  William Shakespeare

* Bad time has scientific value … We learn geology the morning after the earthquake.
  Ralph Waldo Emerson

* The harder you work, the luckier you get.
  Gray Player

* Not failure, but low aim, is crime.
  James Russell Lowell

* The tragedy of life doesn't lie in not reaching your goal. The tragedy lies in having no goal to reach.
  Benjamin E. Mays

* A great man shows his greatness by the way he treats little men.
  Thomas Carlyle

* It is better deserve honors and not have them than to have them and not deserve them.
  Mark Twain

Programmable Logic Controllers (PLCs): Workhorse Of Industrial Automation

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Abstract

Programmable Logic Controller (PLC) also referred to as Programmable Controller (PC) is a solid-state, digital, and industrial computer used for automation of electro-mechanical processes, such as control of machinery on factory assembly lines. Earlier electro-mechanical relays were used to perform logic functions. Unlike personal computers (PCs), the PLCs are designed for multiple inputs and outputs, extended temperature ranges, immunity to electrical noise, and resistance to vibration and impact. Higher-level languages ease the programming task for large systems. PLCs and their unique language, ladder logic, are the workhorses of factory automation.

Keywords: PLC, Ladder Logic, Function block diagram (FBD), Structured text (ST), Instruction list (IL), Sequential function chart (SFC)

I. INTRODUCTION

The National Electrical Manufacturers Association (NEMA) defines a programmable logic controller (PLC) as: a programmable controller is a digitally operating electronic apparatus which uses a programmable memory for the internal storage of instructions for implementing specific functions, such as logic, sequencing, timing, counting and arithmetic, to control through digital or analog input/output (I/O), various types of machines or process [1].

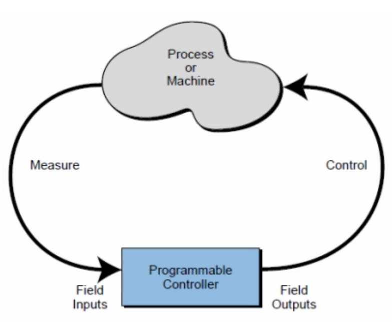

Fig. 1 PLC Conceptual Application Diagram

Fig. 1 shows a conceptual diagram of a PLC application [2]. Often, a single PLC can be programmed to replace thousands of relays. Software to control machines is stored in a battery-powered or non-volatile memory. A PLC is an example of a real-time system since output results must be produced in response to input conditions within a bounded time, otherwise unintended operation will result. These are used for control and operation of manufacturing process, equipment and machinery. It monitors inputs, make decisions based on its program and controls outputs to automate a process or machine [2,4].

II. HISTORY OF PLC

In the 1960s, a typical automated assembly or other manufacturing line had a cabinet of relays wired to control the operation. Before the PLC, control, sequencing, and safety interlock logic for manufacturing automobiles was accomplished using relays, cam timers, and drum sequencers and dedicated closed-loop controllers. The process for updating such facilities for the yearly model change-over was time consuming and expensive, as electricians needed to individually rewire each and every relay. Troubling-shooting (debugging) relay failures was also tedious when so many relays were involved [3,4].

PLCs were developed to replace hard-wired relay logic (*Relay logic* is a method of controlling industrial electronic circuits by using relays and contacts). In 1968, the Hydramatic Division of General Motors Corporation (GM) specified design criteria for the first PLC. Bedford Associates of Bedford won the proposal. The first PLC was designated as *the 084* because it was Bedford Associates' eighty-fourth project. Dick Morley is considered to be the *father of the PLC* as he was one of the people who worked on that project. They Bedford Associates started a new company for dedicated to developing, manufacturing, selling, and servicing this new product: Modicon (MOdular DIgital CONtroller). The *Modicon 084* brought the world's first PLC into commercial use. It is still a popular brand of PLC today, now owned by Schneider Electric. Other well-known PLC brands are Allen-Bradley, ABB, IDEC, Mitsubishi, Siemens, Omron, Rockwell Automation and General Electric [3-4].

The first PLCs offered relay functionality, thus replacing the original hardwired relay logic, which used electrically operated devices to mechanically switch electrical circuits. They met the requirements of modularity, expandability, programmability, and ease of use in an industrial environment. These controllers were easily installed, used less space, and were reusable.

The programming, although a little tedious, had a recognizable plant standard, the ladder diagram format.

Initially most PLCs utilized Ladder Logic Diagram Programming, a model which emulated electromechanical control panel devices (such as the contact and coils of relays) which PLCs replaced [2-3]. The automotive industry is still one of the largest users of PLCs. In a short period, PLCs spread to other industries. By 1971, PLCs were being used to provide relay replacement as the first steps toward control automation in other industries, such as food and beverage, metals, manufacturing, and pulp and paper [2].

III. BASIC PLC OPERATION

PLCs consist of input modules, a central processing unit (CPU) and output modules. Input modules accept a variety of signals (digital or analog) from various sensors and convert them into logic signals that can be used by the CPU. The CPU is the *brain* of the system. It reads input data, executes the stored user program and sends appropriate commands to control devices (output modules - actuators) [4].

The input switch contacts like push-buttons, limit switches, or pressure or temperature sensors have negligible resistance. The output element could be any resistive load e.g., a relay coil, lamp, motor or any other device that can be electrically actuated. The basic operations of a PLC correspond to the combinational control of a logic circuit. In addition, a PLC can carry out other operations such as counting, the processing of signal delays, and a wait for defined time intervals [4]. A PLC must operate in real time. The input and processing of external signals can take place in two ways in a PLC, by polling (repeated requests) or via interrupt signals.

IV. PLC ARCHITECTURE

The architecture of a general PLC is shown in Fig. 2. The main parts of a PLC are its processor, power supply, and input/output (I/O) modules [4].

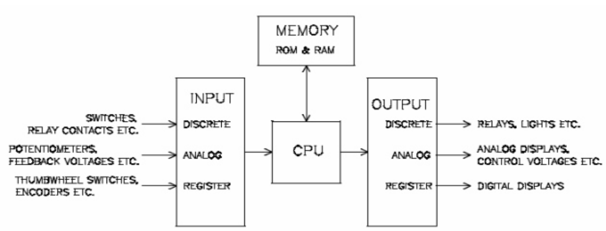

Fig. 2 PLC Block Diagram

The *processor unit* or *central processor unit (CPU)* contains the microprocessor which interprets the program commands retrieved from memory and acts on those commands. The *power supply* unit is needed to convert the AC line voltage to the low DC voltage. The *input module* has terminals into which outside process electrical signals generated by sensors or transducers are entered. The input signals can come from a wide variety of devices, i.e., push--buttons, rotary switches, limit switches etc. The *output module* has terminals to which output signals are sent to activate relays, solenoids, motors and displays. Output modules are generally of two types, *discrete* and *analog*. *Discrete output modules* fall into two classifications, *solid-state switching* and *relay output switching* [3-5].

ADVANTAGES OF PLC

The major advantage of a PLC is that a single circuit with a compact construction can replace a hundred of relays. Secondly, a PLC is programmable and not hardwired so that its operation can be changed with limited effort. On the other hand, PLCs can be slower than hardwired- relay logic [10].

The architecture of the PLC is basically the same as a PC. The main difference from other computers is that PLCs are armored for severe conditions (such as dust, moisture, heat, cold) and have the facility for extensive input/output (I/O) arrangements. These connect the PLC to sensors and actuators. PLCs read limit switches, analog process variables (such as temperature and pressure), and the positions of complex positioning systems. On the actuator side, PLCs operate electric motors, pneumatic or hydraulic cylinders, magnetic relays, solenoids, or analog outputs [7]-[10].

The PLC hardware is built to fit a typical industrial environment, especially regarding heat, humidity, electrical noise, electromagnetic interference (EMI), unreliable power supplies and mechanical shocks and vibrations [5,6,7].

They are easy to use by plant technicians. Hardware interfaces are easily connected. Modular and self-diagnosing interface circuits pinpoint malfunctions and are easily replaced. They are programmed using ladder logic, which is easy to learn. The PLC executes a single program in an orderly and sequential fashion. However, large PLCs have instructions that allow subroutine calling, interrupt routines, and the bypass of certain instructions [5,6,7].

VI. PLC PROGRAMMING LANGUAGES

PLC programming consists of mainly defining control sequences. PLC programs are typically written in a special application on a PC, and then downloaded by a direct-connection cable or over a network to the PLC. The program is stored in the PLC either in a battery-backed-up RAM or some other non-volatile flash memory.

The International Electro-technical Commission (IEC) is a non-profit, non-governmental international standards organization that prepares and publishes International Standards for all electrical, electronic and related technologies collectively known as *electro-technology* [7]. Developed with the input of vendors, end-users and academics, IEC 1131 consists of five parts:

1. General information
2. Equipment and test requirements

3. PLC programming languages
4. User guidelines
5. Communications

IEC 61131-3 is the third part of the open international standard IEC 61131, and was first published in December 1993 by the IEC. The current (second) edition was published in 2003. It specifies the syntax, semantics and display for the following suite of PLC programming languages:

1. Ladder diagram (LD), graphical
2. Function block diagram (FBD), graphical
3. Structured text (ST), textual, similar to the Pascal programming language
4. Instruction list (IL), textual, similar to Assembly language
5. Sequential function chart (SFC), has elements to organize programs for sequential and parallel control processing.

All of the languages share IEC61131 common elements. The variables and function calls are defined by the common elements, so different languages can be used in the same program. One of the primary benefits of the standard is that it allows multiple languages to be used within the same programmable controller. This allows the program developer to select the language best suited to each particular task. While the fundamental concepts of PLC programming are common to all manufacturers, differences in I/O addressing, memory organization and instruction sets mean that PLC programs are never perfectly interchangeable between different makers. Even within the same product line of a single manufacturer, different models may not be directly compatible [7-9].

A. Ladder Logic (LD)

The automotive industry was a major early adopter of PLCs. They wanted a programming method that could be easily understood by their existing controls engineers and technicians. The result of this desire was a programming language called *Relay Ladder Logic* or *ladder logic*.

Ladder logic is a programming language that represents a program by a graphical diagram based on the circuit diagrams of relay-based logic hardware. The name *ladder diagrams* is based on the observation that programs in this language resemble ladders, with two vertical rails and a series of horizontal rungs between them i.e., these programs look like the rungs on a ladder [2-3].

The layout of Ladder Logic is very similar to reading the diagrams for hard wired relay controls. Ladder Logic is still one of the most popular languages for programming PLCs, but many others have developed over the years. With ladder logic, an imaginary relay network is described. If such network were in fact real, the desired control would take place. A ladder logic diagram must be read as symbols not as switch contacts [2-4].

The ladder logic symbology was developed from the relay ladder logic wiring diagram. Consider the simple problem of turning on a lamp when both switches A and B are closed, as shown in Fig. 3(a). Also note that the output for the rung occurs on the extreme right side of the rung and power is assumed to flow from left to right. One would interpret the rung symbology as: When input (switch) A is ON and input (switch) B is ON then the lamp is ON [3].

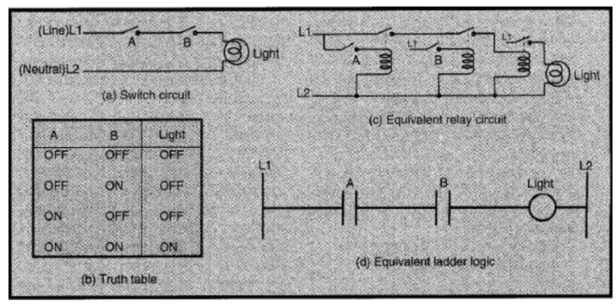

Fig 3 Series Circuit a) Switch circuit, b) Truth table, c) Relay logic, d) Ladder logic

Each rung has a connection to the left (power) rail and a connection to the right (neutral) rail. The rungs of a ladder diagram are *executed* simultaneously in a wiring diagram. Each *rung of* the LD must contain at least one output element; otherwise, a short circuit between power supply and ground will take place. In reality, the ladder logic diagram is only a symbolic representation of the computer program. So, power does not really flow through any actual contacts; however, the concept of power flowing through contacts is useful when explaining the program operation [3].

The three basic ladder logic symbols are: Normally open (NO) contact, Normally closed (NC) contact and Output (relay coil). The *normal state* is the one in which the coil is energized. The output is energized whenever any left-to-right path of input contacts is closed [3]. PLC evaluated the rungs sequentially, usually from top to bottom and from left to right.

One aspect of ladder logic that is often confusing is the use of the NC contact. The contact symbol in the ladder does not necessarily correspond to the actual switch type used in the field. After all, the PLC does not know how the switch is wired in the field, only whether the switch is open (off) or closed (on). So, a NO switch does not require a -I I- in the ladder logic and a NC switch does not require a -I I- in the ladder logic. Regardless of the type of switch in the field, when one wants *action* (something to be logically true, or on) when the switch is closed (on), use the -I I- symbol.

When one wants *action* (something to be logically true, or on) when the switch is open (off), use the -I I- symbol. One must eventually learn to read a ladder logic diagram as symbols and not as relay contacts [3].

There are three classes of ladder logic instructions: *input/contact instructions* and *output/coil instructions*. Input instructions are the contact instructions replace a contact instruction. These instructions are the conditions to turn on the output. In contrast, an output instruction always occurs on the extreme right side of the rung [3-4].

Not all instructions are contacts or coils. All other types of instructions are often called *function blocks* or *box instructions* because that is how they appear in the symbology. Timers, counters, comparison, and computation sequencers, shift registers, and data move instructions are all the most common box instructions.

B. Function Block Diagram (FBD)

is a graphical language for a PLC or a Distributed Control System (DCS). A FBD, as shown in fig. 4, is a diagram that describes a function between input variables and output variables. A function is described as a set of elementary blocks. Input and output variables are connected to blocks by connection lines. An output of a block may also be connected to an input of another block.

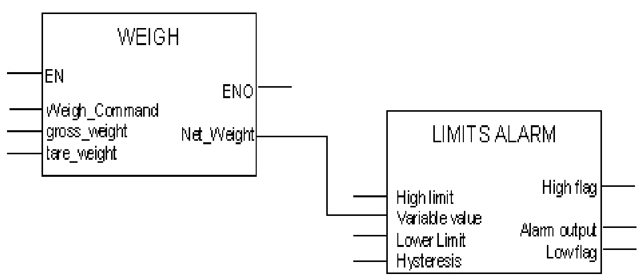

Fig. 4 Function Block Diagram Language

The primary concept behind a FBD is data flow. In these types of programs the values flow from the inputs to the outputs, through function blocks. FBDs use logic gates (AND/OR) for digital signals and numeric function blocks (arithmetic, filters, controllers for numeric signals [2,8,9].

C. Structured Text (ST)

is a structured high level language and syntactically resembles Pascal, BASIC and C. It allows structured programming, meaning that many complex tasks can be broken down into smaller ones i.e., it uses subroutines to perform different parts of the control function and passes parameters and values between the different sections of the program. A simple example is shown in Fig 5 [2,8,9].

```
PROGRAM main
Var
i:INT;
END_VAR
i:=0;
REPEAT
i:=i+1;
UNTIL i>=10;
END_REPEAT;
END_PROGRAM
```

Fig. 5 A Structured Text Example Program

ST also supports iterations, such as WHILE-DO and REPEAT-UNTIL, as well as other conditional executions, such as IF-THEN-ELSE. Problem-oriented ST programming is particularly suited to applications involving data handling, computational sorting, and intensive mathematical applications utilizing floating-point values. It supports Boolean operations (AND/OR). It is also the best language for implementing artificial intelligence (AI) computations, fuzzy logic, and decision making [2,8,9].

D. Instruction List (IL)

Is a low level language like Assembly language. It contains simple mnemonics such as LD, AN, ADD, etc. It is the most fundamental level of programming language - all other programming languages can be converted to IL programs. This type of Assembler-like IL language is useful for small applications, as well as applications that require speed optimization of the program or a specific routine in the program. It is useful in cases where small functions are repeated often and is used to create custom function blocks. Although it is powerful, it is considered to be difficult to learn. Fig 6 shows an IL [2,8,9].

```
LD A
AND   B
STO    LIGHT
```

Fig 6. An Instruction List for Series Circuit of Fig.2

E. equential Function Chart (SFC)

is a graphical technique for writing concurrent control programs. It is defined in IEC 848, *Preparation of function charts for control systems*, and was based on Grafcet (Graphe Fonctionnel de Commande Étape Transition). The three main components of an SFC are steps, actions and transitions. *Steps* are merely chunks of logic, i.e., a unit of programming logic that accomplishes a particular control task. *Actions* are the individual aspects of that task. *Transitions* are the mechanisms used to move from one task to another. Control logic for each Step, Action and Transition is programmed in one of the other languages such as Ladder Diagram or Structured Text. SFCs are suited to processes with parallel operations [2,8,9].

Grafcet is a symbolic, graphic language, which originated in France that represents the control program as steps or stages in the machine or process. In fact, the English translation of Grafcet means *step transition function charts*. It is the foundation for the IEC 1131 standard's SFCs, which allow several PLC languages to be used in one control program. SFCs have been developed to accommodate the programming of more advanced systems. These are similar to flowcharts, but much more powerful. Fig. 7 shows a selection branch, in which only one branch is executed depending on which transition is active [2,8,9].

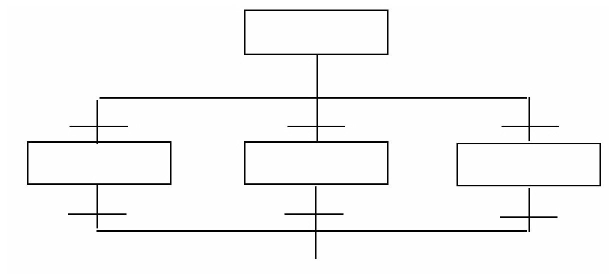

Fig 7 SFC Selection Branch

Basically, Grafcet employs only written action statements whereas SFC implements actions in a number of ways using LD, IL, ST, and FBD or a combination of these languages, including custom function blocks.

VII. CONCLUSION

PLCs are at the forefront of manufacturing automation. Many factories use PLCs to cut production costs and or increase quality of products. IEC 61131-3 deals with programming languages and defines two graphical and two textual PLC programming language standards. When Ladder Logic was seen unable to meet the automation needs of the 21st century, high-level languages emerged. Although other languages are used, ladder logic presently remains the dominant language of automation.

An engineer working in a manufacturing environment will at least encounter PLCs and ladder logic, if not use them on a regular basis. Electrical engineering students should have some know how of PLCs because of widespread use of PLCs in domestic and industrial applications.

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Enhancement In Power Transmission System Using Statcom & SVC Facts Controllers

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1. Introduction

Electricity supply industry has been facing problems in the past many years to achieve the high level performance due to increasing demands. Upgrading of existing power plants, installation of new power plants, environmental effects, deregulation and development of fast-response electronic control devices are the major part of these demands.

Lack of experienced power engineers in the field of Generation, Transmission and distribution affected the design work in electric power systems. Design work depends on various areas of expertise, disciplines, simulations, data and real examples. The single document does not contain all this knowledge, but it is widely scattered. Most of it exists in the mind of human experts. This part of the paper contains the details about the FACTS Device, Particularly STATCOM & SVC type.

The major concerns of the power system operators are the voltage stability and efficiently voltage alteration. It is the ability of the power system to maintain allowable voltage limits at all nodes in the system under normal and emergency conditions. Continuous and unmanageable decrease in voltage may lead to voltage instability condition in a power system. Voltage instability arises due to insufficient reactive power supply from generators and transmission lines.

In order to avoid equipment failure due to the unstable voltage, efficient control is required at all the main point of the network, as transmission of active power requires also requires magnitude of the voltage high enough to support the loads. To control the voltages in a power system, different techniques are used. The paper accentuates the role of two shunt connected FACTS controllers i.e. STATCOM & SVC in regulating the system voltage and improving the overall performance of the system.

2. Objective Of The Research

The objectives of the research are as follows:

1. Study of Power Transmission System & their constraints.
2. Study of Shunt connected FACTS devices i.e. STATCOM & SVC.
3. Application of STATCOM & SVC in a typical power system under heavy loading & fault conditions so as to provide the voltage regulation by generating reactive power.
4. Modeling of the power system with STATCOM & SVC using Simulink Software.
5. Comparison of STATCOM & SVC in enhancing the performance of the overall power system.
6. Simulation Part of this paper will be presented in Part II of this paper.

3. Problem Statement

The overall objective of this thesis is to study the behavior of Shunt connected FACTS devices i.e. STATCOM & SVC so as to provide the voltage regulation under heavy loading and fault conditions by generating reactive power at the point of its connection.

4. Facts Devices

4.1 Background Of Transmission Lines

Three main features of the electric power transmission are: Generation, Transmission and Distribution. Due to the rapid expansion and growth of electrical utility industry, frequent changes are continuously brought in to a final conventional product. Electricity due to the involvement of high level engineering is increasingly considered as a product. As a result transmission systems are overloaded to their stability and thermal limits. However, there are certain limitations on the transmission systems like power transfer between areas or within a single area [2].

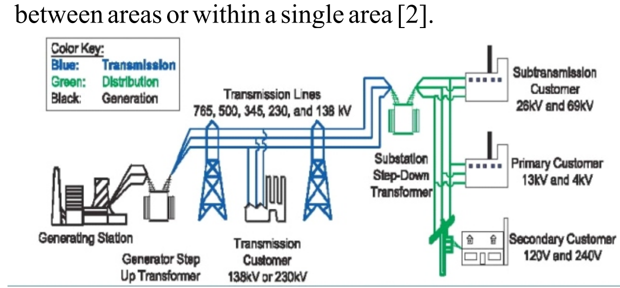

Figure-1: A typical Power System [2].

4.1 Constraints Of Transmission Lines

There are certain limitations on a transmission system that cannot be neglected in any case:

Steady-State Power Transfer Limit Stability problems at energy transfer over long transmission distances.

Voltage stability limit Voltage control at various loading and fault conditions.

Dynamic voltage limit.

Transient stability limit.

Power system oscillation damping limit Reactive power balance (voltage transmission losses).

Unintentional loop flow limit.

Thermal limit.

Short circuit current limit Increase of short circuit power in meshed systems.

Now there are certain conventional techniques available to control these constraints as shown in the table-1 below: **[2].**

Due to high cost, less favorability and heavy construction, these conventional techniques are no more trustworthy. To have operational as well as financial profitability the existing transmission system is required to be more efficiently controlled and utilized. In past, the conventional ways of upgrading the transmission system with new transmission lines was very difficult, expensive and time consuming.

The technology of conventional methods has to enhance a flexible and worst generation capable transmission system. It is of vital importance to utilize the transmission line in an economical manner enabling industrial utilities to remain aggressive and to carry on. The investment in transmission system for its optimal utilization is also important to support industry, create employment and utilize economic resources in the developed countries.

Conventional Transmission Enhancement Techniques	**Impedance control**	**Voltage control**	**Angle control**	**Power Control**
Series Capacitor	✦			
Shunt Capacitor & Reactor		✦		
Transformer Load Tap Changer			✦	
Phase Shifting Transformer			✦	
Synchronous Condenser		✦		

Table-1: Conventional Techniques of Enhancement in Transmission System [2].

To enhance the performance of the existing power system through advanced control technologies and to fulfill all the power demands, flexible ac transmission system (FACTS) is not only a cost effective solution, but proven solution to the way the transmission systems are controlled and developed.

5. Facts Controllers

FACTS devices are the latest technology of power electronic switching devices used for the dynamic voltage control, impedance control, angle control and power control of the transmission lines. Based on the power electronic devices used, there are two types of FACTS controllers: **[3].**

Thyristor based controllers

Converter based controllers Thyristor based FACTS controller includes:

Static VAR compensator (SVC)

Thyristor controlled series capacitor or compensator (TCSC)

Thyristor controlled phase angle regulator (TCPAR)

The first two controllers SVC & TCSC are the major members of this group. Both these controllers employed capacitor or reactor banks, alongwith thyristors as switching elements used to control the reactive impedance by generating or absorbing the required reactive power.

TCPAR do not use any inbuilt capacitor & reactor, but may use for the reactive power support to AC system. As a result, SVC & TCSC present variable reactive impedance indirectly to the transmission system. SVC is a controlled shunt reactive admittance source in which the required reactive current is a function of the system voltage. TCSC is controlled reactive impedance in series with the line in order to develop the compensating voltage i.e. required voltage is a function of line current. Both the controllers do not exchange real power with the AC system. Fig.2 below indicates the application of thyristor based controller in a power system: **[3].**

Converter based FACTS controller includes:

Static synchronous compensator (STATCOM)

Static synchronous series compensator (SSSC)

Interline power flow controller (IPFC)

Unified power flow controller (UPFC)

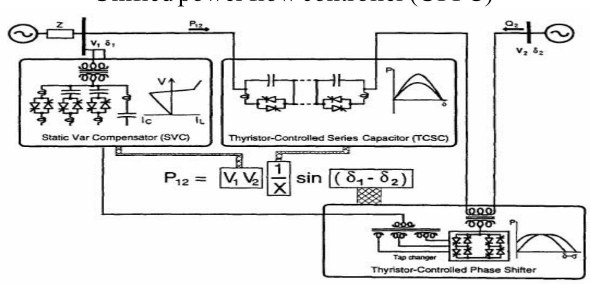

Figure-2: Thyristor based controllers [2].

The converter based FACTS controllers consist of self-commutated, voltage source converters. It is a new generation of transmission controllers. These controllers can provide reactive shunt & series compensating current and voltage, independent of the ac system voltage and current respectively. In addition to controllable reactive power compensation, these controllers can also exchange adjustable real power with the system. A typical application of converter based controllers is as shown in the fig.3 below: [2]

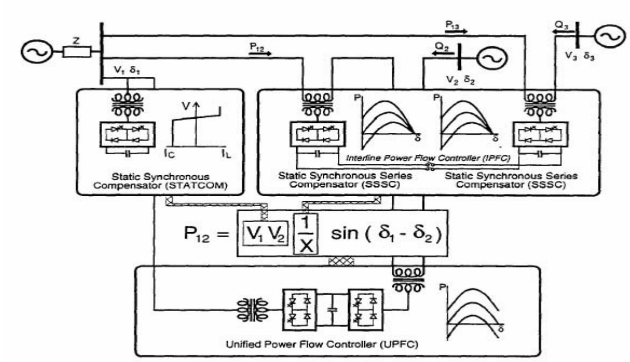

Figure 3: Converter based controllers [2].

So instead of constructing a new transmission line, FACTS controllers can improve the operation of new transmission lines with minimum cost investment, minimum time and minimum environmental affects. FACTS devices can be further classified as shunt, series and shunt-series connected devices as given below: **[3].**

5.1 Shunt Connected:

Static VAR Compensator (SVC)

Static Synchronous Compensator (STATCOM)

Static Synchronous Generator (SSG)

Superconducting Magnetic Energy Storage (SMES)

Static VAR System (SVS)

Static VAR Generator or Absorber (SVG)

Static Condenser (STATCON)

Thyristor Switched Reactor (TSR)

Thyristor Switched Capacitor (TSC)

Thyristor Controlled Reactor (TCR)

Thyristor Controlled Breaking Resistor (TCBR)

VAR Compensating System (VCS)

5.2 Series Connected:

Thyristor Switched Series Reactor (TSSR)

Thyristor Controlled Phase Shifting Transformer (TCPST)

Static Synchronous Series Compensator (SSSC)

Thyristor Controlled Series Capacitor (TCSC)

Thyristor Controlled Series Reactor (TCSR)

Thyristor Switched Series Capacitor (TSSC)

2.3.3 Shunt-Series Connected:

Unified Power Flow Controller (UPFC)

Inter phase Power Flow Controller (IPFC)

The table-2 below indicates some of the FACTS devices w.r.t. their involvement in power system enhancement. **[2]**

The more commonly used FACTS devices are as follows: **[4]**

5.3 Static VAR Compensator (SVC)

It is the first generator of the FACTS family and a shunt connected device. It provides the steady state and transient voltage control by reactive power exchange with the system. It is also used to reduce power swings, flickering and reactive power compensation.

5.4 Static Synchronous Compensator (STATCOM)

STATCOM is a fast response FACTS device comprised of GTOs (Gate turn off thyristors). It provides the dynamic voltage control by reactive power exchange independent of the AC system voltage. It can be based on a voltage source as well as current source converter.

FACTS Devices	Impedance Control	Voltage Control	Angle Control	Power Control
Static Synchronous Compensator (STATCOM)		✦		
Static VAR Compensator) (SVC)		✦		
Unified Power Flow Controller (UPFC)	✦	✦	✦	✦
Convertible Series Compensator (CSC)	✦	✦		
Interphase Power Flow Controller (IPFC)	✦	✦	✦	✦
Static Synchronous Series Controller (SSSC)	✦		✦	✦
Thyristor Controlled Series Capacitor (TCSC)	✦			

Table 2: Type of FACTS Devices w.r.t. to operation [2].

5.5 Thyristor Controlled Series Capacitor (TCSC)

TCSC is used to control the power flow, damping of power oscillations and increase of energy transfer with the help of series capacitor in parallel with controlled reactor. It is an excellent source of series compensation.

5.6 Unified Power Flow Controller (UPFC)

UPFC is actually a combination of static synchronous compensators (SSSC) & (STATCOM) with a common DC capacitor. By means of series voltage injection, it is able to control line impedance and active & reactive power flow through the transmission line.

6. Static Shunt Compensation

Static shunt compensators are used to control the voltage of the transmission line by injecting reactive current at the point of its connection. The impedance of the shunt controller is the main cause of the variable reactive current flow in the line. The shunt controller only supplies or absorbs variable reactive power as long as the injected reactive current is in phase with the line voltage. The major objective of the shunt compensators is to increase the capability of the power to be transmitted from generation to load end in order to make the system stable.

6.1 Static Shunt Compensators Principle of operation

In a practical power system, most of the loads are normally inductive which are the main sources of reactive power. The energy alternately stored or released by the inductors and capacitors are known as reactive power. Reactive power directly affects the system voltages and is the cause of unstable system. The transmittable electric power of the system is defined by the following equation: **[2]**

$$P = \frac{V_1 V_2}{X} \sin(\delta_1 - \delta_2) \text{ ----------------------- } (1)$$

in which

V_1 is the magnitude of sending end voltage

V_2 is the magnitude of receiving end voltage

δ is the phase angle between V_1 and V_2

X is the system impedance

The diagram of the equation is as shown in the fig.4 below:

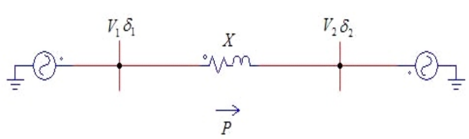

Figure 4: Power Flow Scheme.

The basic principle of the static shunt compensator is to generate reactive power by using a voltage source converter similar to that of a conventional rotating synchronous machine as shown in the fig. 5 below: **[2].**

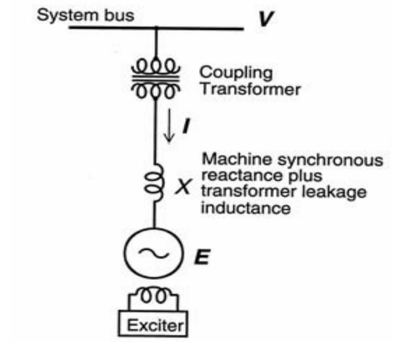

Figure-5: Reactive Power generation by a rotating synchronous compensator [2].

The function of a voltage source converter is to convert DC voltage from the capacitor into three phase AC voltage. Recall the operation of a rotating synchronous machine in which for pure reactive power flow, induced three phase emfs are in phase with the system voltages. The machine draws reactive current from the system which is dependent on the system voltage V, excitation voltage E of the machine and its reactance and transformer leakage reactance plus system short circuit reactance. The expression is as shown below:

$$I = \frac{V\ E}{X} \text{ -----------------------} (2)$$

The reactive power exchange can be expressed as follows:

$$Q = \frac{(1\ E/V)\,V^2}{X} \text{ ------------- } (3)$$

The flow of the reactive power can be controlled by the excitation voltage of the machine (E) comparative to the system voltage (V). Increasing amplitude of E above V will make the machine operating an over excited condition resulting into a leading current and capacitive mode of the machine. Decreasing E below V will make the machine operating in an under excited condition resulting into a lagging current and inductive mode of the machine, Thus the shunt compensation is used to control the voltage of the transmission line by generating or absorbing capacitive and inductive current respectively in order to maintain the system disturbances and emergency conditions. Basically the requirements for the compensation are of two types: **[5].**

1. **Direct voltage control** to maintain the system voltage under heavy loading conditions.
2. **Transient & Dynamic voltage control** to maintain the system voltage under fault conditions and to provide the power oscillation damping.

Static Shunt Compensators Major requirements

Shunt compensating devices have the following major requirements: [2]

1. Static synchronous compensator should be able to deal with all kind of situations like major disturbances in the form of faults etc at the bus of the AC system to which it is connected to provide the shunt compensation. In case of any nearby fault causing drastic decrease in bus voltage, the static synchronous compensator must be able to restore the bus voltage immediately after fault clearance.
2. Static synchronous voltage should be able to regulate the bus voltage by injecting or absorbing reactive power as required by the system conditions in order to improve transient stability and power oscillation damping.

Hence the shunt compensation provides the following main operations:

1. Reactive power control of dynamic loads
2. Steady State and dynamic voltage control
3. Damping of active power oscillations
4. Improvement of system stability

6.2 Static Shunt Compensators Application

Shunt compensation technique is the backup to the defects in the series technique, mostly in the voltage control because of its location in a system. Table below indicates the applications of some different type of shunt compensators w.r.t. the corresponding short circuit level and the transmission phase angle. **[2,4]**

Mechanically switched reactor (MSR) and Mechanically switched capacitor (MSC) devices also belong to the shunt compensation family. Table clearly shows that STATCOM & SVC are better in performance as compared to the other devices **[5]**.

7. Static Synchronous Compensator (STATCOM)

STATCOM is an advanced version of shunt connected SVC and has a faster response than SVC in regulating system voltage by generating capacitive & absorbing reactive current independent of the AC system voltage. This is because in the event of sudden change in the system voltage, the capacitor voltage does not change instantly. Thus STATCOM is very effective in cases where immediate response is required for the desired changes. **[1, 2].**

STATCOM consists of voltage source converter with self commutated semiconductor devices such as GTOs, IGBTs, IGCTs, MCTs etc. This makes the STATCOM much capable of high dynamic performance as compared to SVC with controllable reactors and switched capacitors. **[1]**

Major advantages of STATCOM over SVC are:

1. Faster Response
2. Less in size & weight
3. Inherently modular & re-locatable
4. Cost reduction
5. Active harmonic filter capability
6. It can be interfaced with real power sources such as battery, fuel cell etc.
7. It can provide maximum capacitive & inductive current at any system voltage.

Previously the STATCOM was called as Static synchronous condenser (STATCON) due to the same principle of operation.

7.1 Configuration Of STATCOM

STATCOM is comprised of three main parts as indicated in the fig.6 below: **[1,2].**

Voltage Source Converter (VSC)
Coupling Transformer.
External Controller

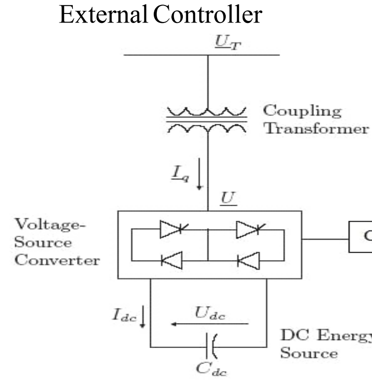

Figure 6. Configuration of STATCOM [2].

A voltage source converter is used to convert the DC voltage of a capacitor into three-phase AC voltage with the help of GTO (Gate turn-off) switches i.e. the magnitude of the voltage can be controlled by controlling the firing angles of the GTOs. A three phase, three pulse VSC is as shown in the fig. 7 below: **[2].**

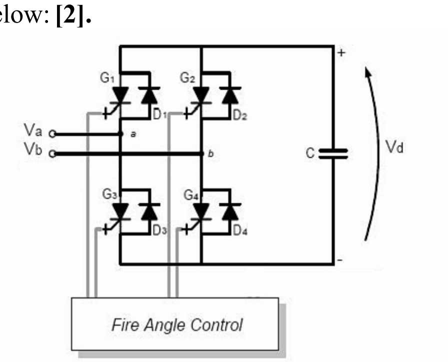

Figure 7. Three-Pulse Voltage Source Converter [2].

NOTES

The configuration consist of three GTOs connected anti-parallel diodes with a DC source probably the small charged capacitors.

A coupling transformer is used to connect the VSC to the AC power system. The leakage reactance/inductance of this transformer is used to filter the current harmonics normally generated due to the energy stored in the capacitor and pulsating output of the VSC.

The function of external controller of the STATCOM is to synchronize the converter output voltage with the system voltage in such a way so that the STATCOM generates or absorbs required reactive power at the point of its connection.

7.2 Basic Operating Principle Of STATCOM

Refer to the fig.8 below:

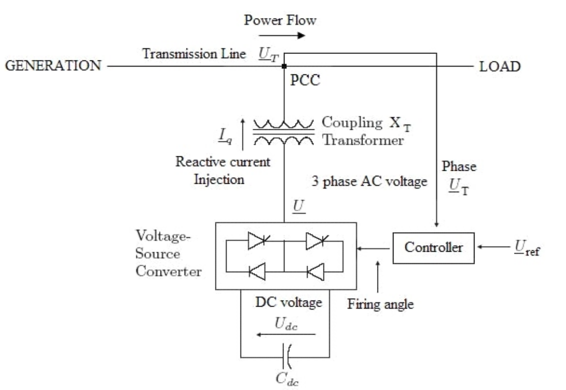

Figure 8. Operating Principle of STATCOM [1].

A power system shown has a deregulated voltage due to which a STATCOM has been shown connected at the point P through a step up coupling transformer. The external controller of the STATCOM is controlling the firing angle of the switching GTOs of the converter to control the magnitude of the converter output voltage. A STATCOM is a controlled reactive power source by generating or absorbing the reactive power at the point P **[1].**

The charged capacitor C_{dc} produces the DC output voltage V_{dc} to the converter which then produces a set of controllable three phase output voltages V. The voltages V are in synchronism with the AC system voltages performed by an external controller. The controller is actually performing the matching of the voltage V_T with V_{ref} by controlling the firing angles of the converter. The voltage V_{ref} is set manually to the controller. I_q is the reactive current injected by the STATOM into the system which is actually the current produced from the capacitor by absorbing real power from the AC system. The expression of the reactive current is as follows: [1, 2].

$$I_q = \frac{V_T \; V_{eq}}{X_{eq}}$$

Where:

I_q = Reactive current injected by the STATCOM

V_T = Terminal voltage of the STATCOM

V_{eq} = Equivalent thevenin voltage seen by the STATCOM

X_{eq} = Equivalent thevenin reactance of the system seen by the STATCOM

Mode of STATCOM will be capacitive in case reactive power is generated and a leading current is produced i.e. this is the case when amplitude of the voltage V is greater than the system voltage V_T. Conversely, if amplitude of the voltage V is less than the system voltage V_T STATCOM mode will be inductive, lagging current will be produced and reactive power will be absorbed. If amplitude V is equal to V_T, no power exchange will occur. **[2, 4].**

Like any other electrical device, a practical converter also has some internal losses i.e. it is not lossless. These appear as the energy stored in the DC capacitor. To balance these losses, a small amount of active power has to be absorbed from the system. This can be done by making output voltage of the converter slightly lags the system voltage by an angle ä. [2]

The four quadrant phasor diagrams of the STATCOM operation are as shown below in fig. 9:

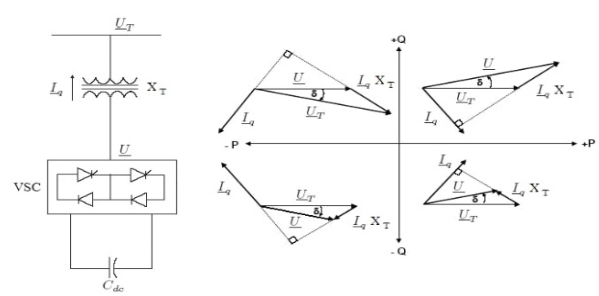

Figure 9. Phasor Diagram of STATCOM [2].

A battery can also be used as a DC source instead of capacitor. Which then make the converter able to control reactive as well as active power. This could be very useful in the cases where control of active power flow is required and to damp the power oscillations in the system **[2].**

7.3 Characteristics Of STATCOM

The two modes of operation of STATCOM are: **[1]**

1. Voltage regulation mode
2. VAR control mode

In voltage regulation mode, STATCOM has the followi

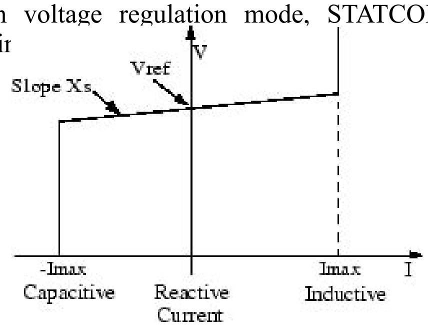

Figure 10. V-I Characteristics of STATCOM [1].

$-I_{max}$ Capacitive & I_{max} Inductive indicates the maximum and minimum values of the reactive currents. Now as these currents are within the range as shown in the characteristics above, voltage will remain regulated at the reference voltage V_{ref}. The slope Xs can be adjusted within 1% to 4%. In voltage regulation mode, the V-I characteristics of the STATCOM can be defined with the following equation: **[1].**

$$V = V_{ref} + X_s . I$$

Where:

V = System Voltage

I = Reactive current of the STATCOM

X_s = Slope reactance

V_{ref} = Reference voltage to the converter

From the characteristics it is quite clear that STATCOM can maintain the full reactive current independent of the system voltage.

7.4 Application Of STATCOM

Typical application of the STATCOM can be found in utilities with weak grid loops or having fluctuating reactive loads. However some other applications are as follows: **[1, 2].**

1. Unbalanced loads
2. Arc furnaces
3. Wind farms (normally use induction generators of low Power factor against which a STATCOM can be used to improve both steady state and dynamic characteristics of the wind network)
4. Wood chippers
5. Welding operations
6. Car crushers
7. Industrial mills
8. Mining shovels
9. Harbor cranes

Further the application of STATCOM is found to prevent damaging of over-voltages that may occur due to isle conditions.

7.5 Advantages Of STATCOM

The main advantages of the STATCOM are: [1,2].

1. Continuous & dynamic voltage control
2. High dynamic & very fast response time (the response is much faster to changing system conditions)
3. Enables grid code compliance
4. Maximum reactive current over extended voltage range
5. High efficiency
6. Single phase control for unbalanced loads
7. Small footprint
8. It does not contribute to short circuit current
9. Symmetric lead-lag capability
10. No moving parts, maintenance is easy
11. No problem of loss of synchronism in case of major disturbance

8. Static VAR Compensator (SVC)

SVC is a first generation of FACTS controllers. It consists of anti-parallel connected thyristor valves configuration with a reactor through which a current can be controlled making SVC a variable impedance device. Basically thyristor valve technology of SVC is advancement in HVDC technology. The major difference is that SVC is connected to a transmission system through step down transformer, so the thyristor valves of lower voltages are required for this. Often these thyristor valves are connected to the tertiary winding of a power transformer **[1].**

Initially SVC was used for the load compensation of the frequently changing load conditions found in steel mills, arc furnaces etc. Later the objective of the device is to provide dynamic power factor improvement and voltage control. These applications of the SVC were started in the late seventies **[3].**

Major objectives of the SVC are:

1. To improve power transfer over long lines
2. To improve system stability by providing voltage control

3. To dampen the low frequency oscillations due to power swings
4. To damp frequency oscillations due to torsion modes.
5. To provide dynamic voltage control

SVC is based on simple inductive and capacitive elements. The control function is comprised of simple power electronics devices. It has no inertia i.e. it is not based on any rotating machine like synchronous condensers **[3].**

8.1 Configuration Of SVC

SVC is comprised of following major components:

Coupling Transformer

Thyristor Valves

Reactors

Capacitors

SVC provides the voltage regulation at the point of its connection by injecting or absorbing the reactive power form the power system. When the power system voltage is low, SVC will generate reactive power and its mode will be capacitive, conversely when system voltage is high, SVC will absorb reactive power from the system and its mode will be inductive. This control of reactive power is performed by switched capacitors and controlled reactors **[3]**.

The two main configurations of the SVC are:

1. Fixed Capacitor- Thyristor controlled reactor (FC-TCR)
2. Thyristor switched capacitor Thyristor controlled reactor (TSC-TSC)

Thyristor controlled reactor (TCR) with the help of a reactor is used to control the fundamental-frequency current component by delaying the closing of the thyristor switch w.r.t. natural zero passages of the current. The circuit of a FC-TC

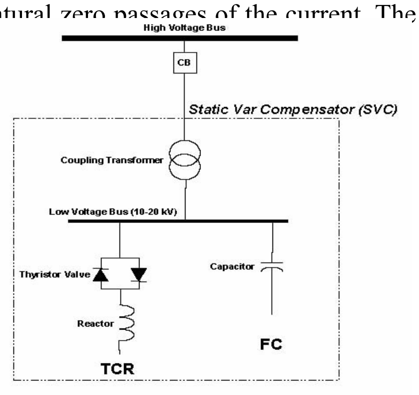

Figure 11: Configuration of FC-TCR [3].

TCR is made of a fixed reactor and an anti-parallel thyristor valve as shown in the fig. 12 of single phase TCR below. By methods of firing delay angle control, the current th … to ze

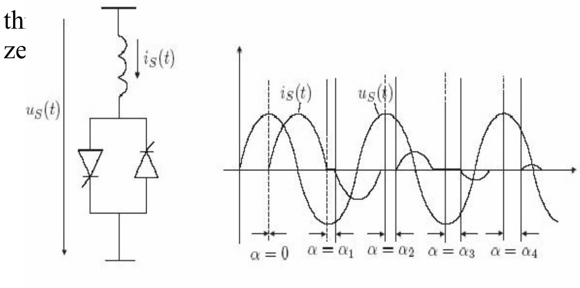

Figure 12. Single-Phase TCR [2].

The duration of intervals related to the current conduction can be controlled by delaying the closure of the thyristor valve with respect to the peak of the applied voltage in each half cycle.

As shown in the fig. above, for á = 0? the amplitude of the voltage is at its maximum and for á = 90? the amplitude is zero i.e. no current is flowing during that half cycle. Thus current through the reactor is achieved by firing the thyristor at desired conduction angle [2].

The basic concept of TSC is used to divide a capacitor bank into small capacitor steps of adequate size and switching on-off of these steps individually using anti-parallel switching thyristors configuration.

Unlike TCR, TSC can be switched out at zero passage of th … the fig. 13 be

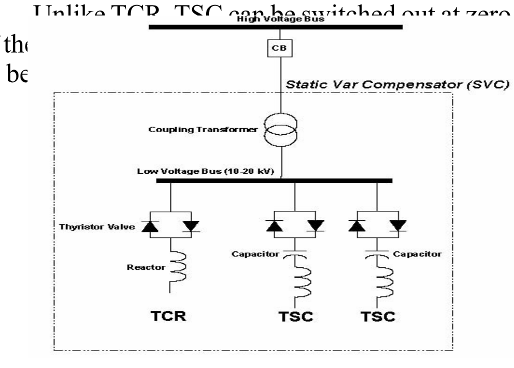

Figure-13 Configuration of TSC-TCR [3].

As shown in fig. 14 below, when the current is passing through zero, capacitor becomes fully charged and reached its peak value. In the second mode, the disconnected charged capacitor ideally stays at peak value. Now the

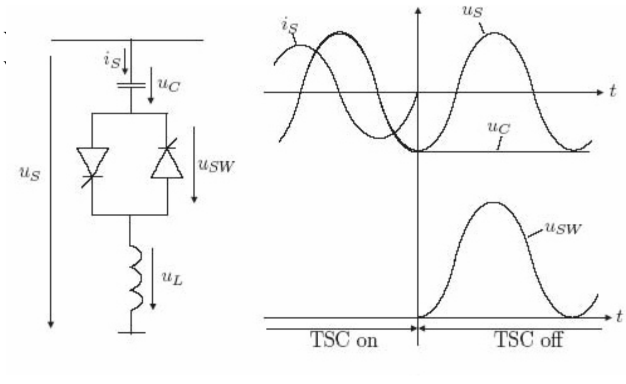

Figure 14. Thyristor Switched Capacitor [2].

At the time the thyristor is switched out, the voltage across the capacitor immediately discharged after disconnection. Now as the voltage across the conductor is equal to the AC voltage, the re-connection of the capacitor rakes places i.e. the instance when the voltage across the thyristor valve is zero [2].

The switching of the capacitor may introduce transient disturbances which could result in an instantaneous current in the capacitor. In order to minimize these transients capacitor switching must occur at some specific instants in each cycle. Therefore a current limiting reactor has been placed in the branch to minimize the current in the capacitor that would occur due to its switching. Hence TSC is a capacitive admittance device which is either connected to or disconnected from the AC system [2].

8.2 Characteristics Of SVC

The modes of operation of SVC are:

1. Voltage regulation mode
2. VAR control mode

ving V-I

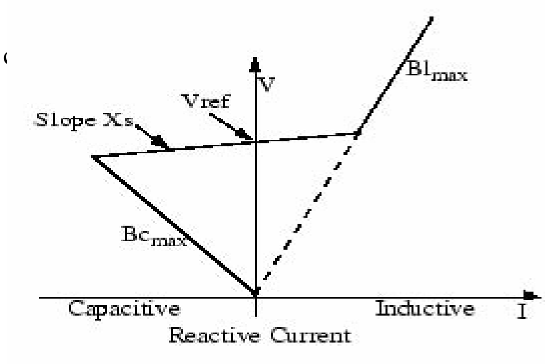

Figure-15. V-I Characteristics of SVC [1].

-Bc_{max} and Bl_{max} indicate the maximum and minimum values of the susceptance required by the total reactive power of capacitor & reactor banks. Now as these susceptances are within the range as shown in the characteristics above, voltage will remain regulated at the reference voltage V_{ref}. The slope Xs can be adjusted within 1% to 4%. In voltage regulation mode, the V-I characteristics of the SVC can be defined with the following three equations: **[1].**

$V = V_{ref} + X_s.I$

$V = - I/Bc_{max}$

$V = I/Bl_{max}$

Where

V = System Voltage

I = Reactive current of the SVC

X_s = Slope reactance

V_{ref} = Reference voltage to the converter

Bc_{max} = Maximum capacitive susceptance with all TSCs in service

Bl_{max} = Maximum inductive susceptance with all TCRs in service

8.3 Applications Of SVC

The major applications of the SVC are: **[1,2].**

1. Rapid voltage regulation
2. Control of temporary over-voltages on load rejection, faults or other transient disturbances
3. Compensation for flicker
4. To extend the stability limits by providing the voltage boost within a transmission system
5. To provide the dynamic voltage support at weak points in meshed transmission networks
6. To contribute to the reduction of harmonics distortion in a system
7. To damp low frequency oscillations at high loading conditions
8. To balance single phase loads
9. To permit greater flexibility in planning the supply of reactive power in power systems by the ability to relocate static compensators.
10. To extend the transmission distance while maintaining acceptable operating voltages at any load.

8.4 Advantages Of SVC

The main advantages of SVC are: **[1].**

1. Faster response under transient conditions
2. Cost effective solution
3. Effectively improve voltage control
4. No moving parts, hence requires less maintenance
5. No problems related to loss of synchronism
6. No contribution to short-circuit currents

8.5 Comparison Between SVC And STATCOM

Both SVC and STATCOM are fast response shunt compensators, their comparison can be made with the help of V-I characteristics: **[1,2].**

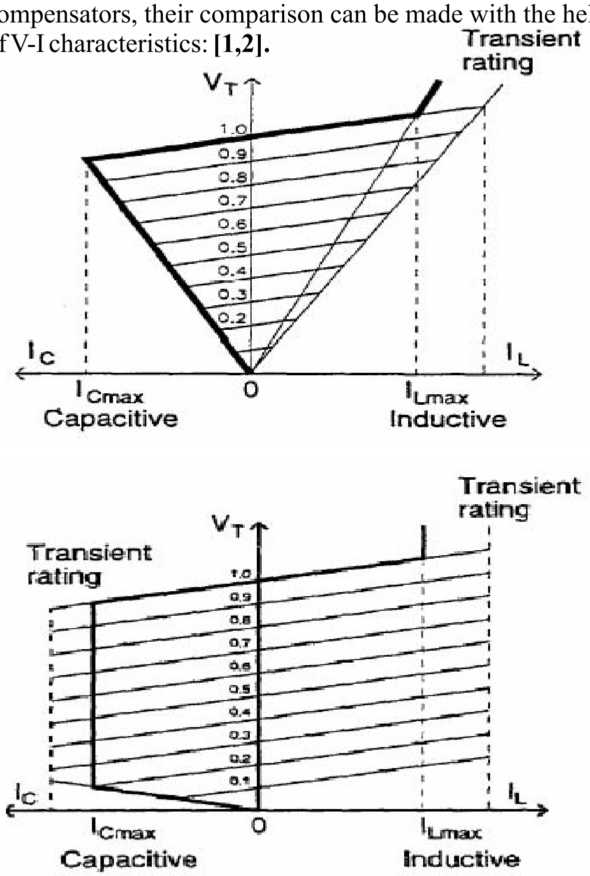

Figure 16. V-I Characteristics of SVC (left) & STATCOM (right) [2].

It is quite clear from the V-I characteristics that the STATCOM has more capacitive and inductive current range as compared to SVC and is capable of providing more output current than SVC. Moreover STATCOM can provide full capacitive output current at any system voltage, even down to zero, whereas SVC provides only moderate output current with the decreasing system voltage **[2]**.

Furthermore, it is obvious from the characteristics that the transient rating of the STATCOM is greater in capacitive & inductive regions whereas the transient rating of the SVC is dependent on the size of the capacitor **[2].**

In addition STATCOM provides the much faster response than SVC because STATCOM do not possesses any kind of delay in firing of thyristors and this is only because of a voltage-source converter **[2].**

9. Simulation And Analysis Of Static Synchronous Compensator (STATCOM)

9.1 Voltage Regulation Of 500/230 Kv Network With STATCOM

The power system in which a STATCOM is installed to control the voltage is a 500 kV /230 kV transmission systems, connected in a loop configuration, consists of five buses (B1 to B5) interconnected through transmission lines (L1, L2, L3) and two 500 kV/230 kV transformer banks Tr1 and Tr2. Two power plants are located on the 230-kV system generate a total of 1500 MW which is transmitted to a 500-kV 15000-MVA equivalent and to a 300 MW, 300 MVAR & 200 MW, 200 MVAR RL load connected at buses B2 & B3. The plant models include a speed regulator, an excitation system as well as a power system stabilizer (PSS). Tr2 is considered as bank of 3 x 400 MVA Transformers, but in here a contingency case has been taken in which 2 x 400 MVA transformers are in operation. The single line diagram

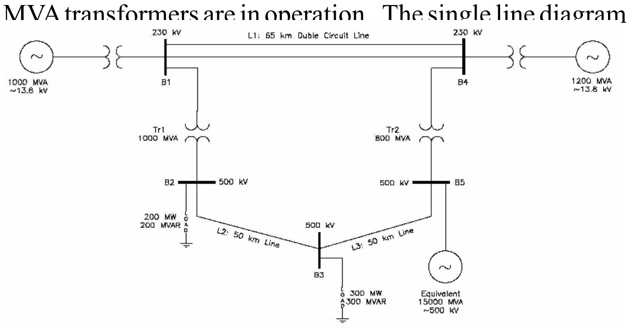

Figure 17. Single Line Diagram.

10. Conclusion

The operation of power system today is getting more complex due to the involvement of lot of controls at different levels i.e. at generation, at transmission and at distribution end. Some of these operations have to be controlled manually by the operator and his rapid decisions are required in this regard. So the need of the hour is to develop an automated system so as to minimize the human eye errors by operators resulting into an unstable system. FACTS devices provide proven technical solutions and measure the changes in the system automatically and alter the way system are developed and control together with improvements in asset utilization, system flexibility and system performance.

Pakistan's EHV system is an essentially North-South radial line network, with the main load centres being situated largely at the two ends. Even as this may appear to be a basic view of the transmission system, it helps in certain considerations, given that the Northern areas are seasonally generation intensive and the Southern end has large fossil fuel fired and nuclear generation. This indicates the necessity of an operational ability to exchange power to needs at both ends of the country, not simply to satisfy the overload demands, but also to promote stability across subsystem boundaries such as that of WAPDA grid and KESC EHV network.

In order to promote overall increase in transmission capability and stability margin alongside oscillation damping to such network shunt compensation is a useful option near the two load ends for transient & dynamic stability improvement.

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5. S. Sadullah, “Enhancement of Power Transmission through HVDC & SVC Technology”.

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Quotation

* Men of genius do not excel in any profession because they labor in it, but they labor in it because they excel.
  William Hazlitt

* Nothing great will ever be achieved without great men, and men are great only if they are determined to be so.
  Charles de Gaulle

* To escape criticism - do nothing, say nothing, be nothing.
  Elbert Hubbard

* A horse never runs so fast as when he has other horses to catch up and outpace.
  Ovid

* The beginning is the most important part of the work.
  Plato

* Ask, and it shall be given you; seek, and ye shall find; knock, and it shall be opened unto you
  Matthew

* When you soar like an eagle, you attract the hunters.
  Milton s. Gould

* To do great things is difficult, but to command great things is more difficult.
  Friedrich Withelm

* It is more difficult to praise rightly than to blame.
  Thomas Fuller

IEEEP Seminar Reform & Restructuring of Pakistan Power Sector

Pakistan Power Sector Reforms Strategic Plan

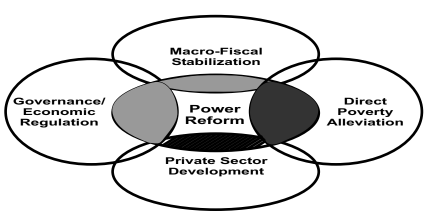
Government of Pakistan approved a Strategic Plan for Restructuring of the Vertial-Monolithic Power Sector to form distinct autonomous entities for Generation, Transmission and Distribution as follows:

- Restructuring of Unified Power Wing of WAPDA into public limited companies under the corporate law, separating Generation, transmission and Distribution functions.
- Create autonomous commercial entities through the adoption of prudent business practices, enhanced efficiency levels, cost reduction and profit orientation.
- Promote competition to eventually offer affordable electricity to customers.
- Through corporatization/commercialization process, promote commercial viability and enhance the business value of the assets block of each corporate entity, and
- Enhance privatization initiatives

Reform & Restructuring Program

- The GoP approved Pakistan Power Sector Strategic Plan, prepared by the International Resource Group, for Restructuring and Reform in 1992, according to which, the Power Wing of WAPDA was structured in 1998 into four (4) Generation Companies (GENCOs), one (1) National Transmission and Dispatch Company (NTDC) and nine (9 Distribution Companies (DISCOs).
- PEPCO was established in 1998 as a management company with mandate to restructure Pakistan Power Sector, corporatize & commercialze the restructured entities and prepare them for privatization. This was to be realized by bringing about reforms thru introduction of competition, enhancement of efficiencies and best financial & prudent utility practices.

Multi-dimensional Reform Framework



PEPCO Mandate

- Independently and without outside interference, control and manage the conversion of the companies into properly structured and efficiently operating power utilities. Do so under Companies through Ordinance, 1984, by:
  - Implementing PEPCO's control over the Companies through revamping their Board of Directors.
  - Creating commercial and financial skills and structures within the companies which were lacking in WAPDA's Power Wing; and
  - Developing and instituting a management change programme to change the culture of the managers from public sector development functions into a commercially - oriented corporate culture based on efficiency, economy, responsibility and accountability.
- Develop the outlines of a competitive, modern and dynamic power sector, which meets the ends of the consumer in the cheapest and most efficient manner. Ensure that the restructuring and reform of WAPDA's Power Wing leads to such a vision.
- On the basis of detailed financial analysis allocate the existing WAPDA deficit to WAPDA and new companies and develop proposal to deal with the deficit/surpluses thus identified.
- Identify the true extent of technical and non-technical losses in the WAPDA system and propose remedies.

Pakistan Power Sector Reforms Strategic Objectives

- Enhance capital formation for the Pakistan Power Sector outside the Government of Pakistan budget and without sovereign guarantees.
- Improve the efficiency of the Pakistan Power Sector through competition, accountability, managerial autonomy and profit incentives, and
- Rationalize prices and social subsidies while maintaining certain socially desirable policies such as rural electrification and low income 'lifeline rates'

Reforms & Restructuring Program Implementation

- PEPCO initiated the restructuring and reform process in 1998. The reform process was gradual for smooth and ripple fee implementation. All the fourteen corporate entities are functioning independently under their own BODs with three Members from private sector including the Chairman.

= However, the Chairmanship and the position of CEO PEPCO remained with the Chairman WAPDA and the Member (Power) WAPDA respectively.

= The situation remained so due to various reasons - however, most of the facets of DISCOS/NTDC and GENCOs operations were duly taken over by the Corporate entities.

= GoP took a review of the Reform Program in October 2007 and decided to separate the management PEPCO outside the influence of WAPDA primarily to pave the way of conclusion of the Reform Process.

= The GoP thru an Executive Order in October 2007, bifurcated the Power Wing of WAPDA and placed its functions under the management of PEPCO including all the Corporate Entities except hydro power stations.

= GoP has required PEPCO now to carry out additional duties:

  ✓ To arrange the earlier and the new additions to the portfolio of IPPs (both under the 1994 and the 2002 Policies) through implementation of the LAs/PPAs

  ✓ To plan and coordinate efforts to mitigate power shortages

  ✓ To plan and coordinate efforts for financial sustain ability

  ✓ To act as the window for handling prospective investments for RPPs, CPPs and IPPs (below 50 MW)

Corporatization & Commercialization Reform Status

= Incorporation of Corporatized Entities under Companies Ordinance and constituting the respective BODs

= Re-vamping the management through induction of professionals through process of executive search and selection.

= Implementation of Manpower Transition Program

= Development of Corporate Management Structure

= Human Resource Management and Actuarial Studies.

= Technical studies towards developing the Grid Codes, Consumer Codes, Performance Standards, Distribution Codes etc.

= Resolution of Tax issues and developing enabling legal framework.

= Transfer of shares and obtaining NEPRA Licenses.

= Transfer of Assets & Liabilities from WAPDA to Companies.

= Facilitation towards Tariff determination.

= Financial Restructuring of the Companies

= Development of FRP, FIP and Business Plans for the Companies

= Transfer of Loans and Lenders consents

PRESENTLY

= All fourteen corporate entities are in place & functioning independently under their own BODs with at least three members out of seven from private sector including the chairman belonging to Business, Agriculture and Trade Community

= Facilitation to Privatization Commission in the Privatization process of Jamshoro Power Generation Company, Faisalabad Electric Supply Company & Peshawar Electric Supply Company.

Corporatization & Comercialization Post Restructuring Scenario

= Conclusion and review of corporatization process by 31 December 2010

  ✓ Conclusion of Manpower Transition Program

  ✓ Development of Manuals of Human Resource Management and Office Management for Companies, such as Service Rules, delegation of financial powers for GENCOs

  ✓ Development and implementation of Corporate Pay Structure

  ✓ Review of Organizational Structures

  ✓ Launching of Integrated Human Resource Development Plan

  ✓ Final search and selection of corporate management positions

= Monitoring of performance contracts

= Serving as interface for corporatized entities with Stakeholders

= Developing outline of the competitive power market

= Handling of outstanding issues/disputes arising out of past transactions between corporate entities and WAPDA, IPPs

= Capacity enhancement and planning on short, medium and long term basis with reference to future of RPPs

= Revamping of existing generation capacity - maximize out put

= Privatization, coordination of select corporate entities and implementation of BESOS

= One-Window handling of prospective investors for RPPs, SPPs and CPPs.

= Formulation of standardized policy for the company operations.

= Negotiation and implementation of Business Plans

= Strengthening of Strategic Corporate Planning Units

= Set up Corporate Planning Departments in corporate entities.

= Corporate financial model for 5 to 15 years projections.

= Project Management, monitoring and implementation of ADB, WB and other MLDA Projects.

= Analysis and technical, commercial and financial audit of DISCOs/NTDC/GENCOs operations

= Crisis management (including the present floods)

= Load management at centralized level (additional role of PEPCO in the existing energy crisis)

= Coordination formulation of the National Power Plan by NTDC for determination of Least Cost Generation Expansion plan and Transmission Expansion Plan for a period upto 2030.

= Based on the NPP, firming up of a Generation Plan for offering to the private sector

= Liaison with the Planning Commission of Pakistan for the formulation of the 10th Five Years Plan.

Central Power Purchasing Agency (CPPA)

= According to NEPRA License, CPPA (Central Power Purchasing Agency) was established in NTDC and the system is operating under single buyer plus model.

= Separate CPPA set up made available, organogram firmed-up/staff needs partially fulfilled

= The position of CEO CPPA is being looked after by a senior professional, while the vacancy has been re-advertised

= As soon as the CEO is in position and a seed money equivalent to two months billing is provided to CPPA, it will start functioning as envisaged

= The target date is June 2011

= Overall management of the separately incorporated CPPA will remain with the NTDC as per the NTDC License issued by NEPRA.

= Incorporation under Companies Ordinance and manning of Corporate Management positions

= Operationalizing Data Centre.

= Re-organization of CPPA and WPPO for final CPPA organization

= Developing CPPA Rules of Business.

= Finalization of GENCOs Power Purchase Agreements

= Finalization of DISCOs Power Sale Agreement

= Commencement of Operations as an entity within the license of the NTDC.

Constraints to conclude Reform Process

= Capacity Short Fall - ensuing Load Management requiring capacity additions

= Financial sustainability - requirement to rationlize tariff(s)

= Now substantial ground has been covered and it is very close to its conclusion.

= However, due to unfavourable generation mix (oil 40%), and consumer mix (strongly in favour of life-line and agri tubewells), the viability and affordability of consumer-end tariff has been eroded.

= Step need to be taken by the Govt to take care of its socio-political obligations without any burden on the utilities.

New Thrust of Reforms

= Capacity Additions as per National Power Plan

  ✓ Private Sector IPPs

  ✓ Extension/additional units in the existing Public Sector GENCOs Power Stations

  ✓ Replacement of the existing de-rated and inefficient GENCOs Plants by state of the art new plants

  ✓ Installation of new Combined Cycle Power Plant in the premises of the retired/abandoned Plants

= Development of Power Parks

  ✓ New Power Stations based on Gas / Oil

  ✓ New Power Station based on Coal (Imported/Local)

= Transmission and Distribution Infrastructure up-gradation, modernization and development-

Development mode can be public, private or public-private partnerships

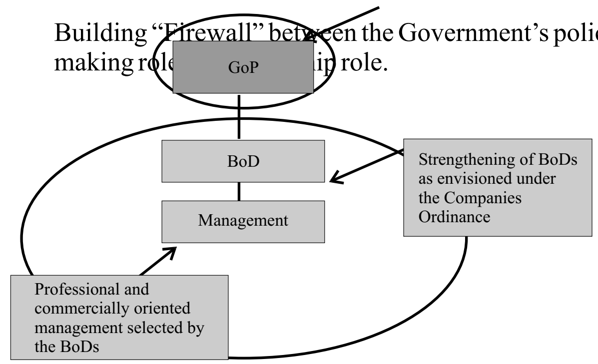
- = Improving Governance and Management of the Companies through
- = Creation of legal and political space required by the Companies to be able to operate in a commercially rational manner
- = Establishment of Full Cost Recovery Tariffs
- = Modernization of Distribution System by incorporation of GIS catering for Asset Management, Area Planning, Load Management, Outage & Customer Complaint Management etc.
- = Augmentation, Improvement and Capacity Expansion of DISCOs distribution network and NTDC transmission network under 5 years rolling plan
- = Enhanced capacity additions to GENCO to ensure fill-in gaps in the NPP - to incentivize private sector investments through CPPs, etc.
- = Improving the Governance through
  - ✓ Inculcation of transparency and meritocracy
  - ✓ Eradication of Theft - Declaration of year 2010 as “Eradication of Theft year”
  - ✓ Eradication of Corruption - Strengthening accountability and oversight
  - ✓ Implementation of integrated Human Resource Development Plan through upgrade HR and competency levels thru intensive training, change management, career planning, and new induction.
  - ✓ Re-engineering of business process and operations
  - ✓ Improved customer services
  - ✓ Incentivizing various operations-specially losses and recoveries

Key Issues and Challenges in Power Sector

- = Institutional and Structural Fragmentation
- = Incomplete unbundling and Corporate Governance Issues in the Power Sector
- = Stalled Privatization
- = Regulatory Challenges
- = Inefficient and Below-Cost Recovery Tariff Structures
- = Lack of Finance for Projects or sustainability of the Power Sector
- = Efficiency Losses
- = Need for Gas Sector Investments
- = Renewable Energy Generation Challenges

Governance Issues Strengthening Corporate Governance

Building “Firewall” between the Government’s policy making rol[illegible]ip role.



Role of PEPCO and its substitution

- = Over a period of time, PEPCO has developed a huge repository of utility management, which cannot be shifted or created in a new organization
- = Mostly incoming new generation is Thermal, based on coal, gas and oil, but there is no thermal development in the country as GENCOs do not have the capacity for development and WAPDA has the mandate for only Hydro Projects. PEPCO was helping GENCOs in carrying out the development functions.
- = Currently, PEPCO is the intervening body between the Government and the Power Sector Companies
- = Number of functions performed by PEPCO are fairly large
- = If PEPCO is disbanded, immediate vacuum will be created, which may cause a collapse of the Power Sector. Similar to the fate of devolution in the Local Bodies.
- = The main role of PEPCO, oversight, coordination and mointoring, will have to be either taken up by the Ministry itself or will have to form another formation to carry out these functions
- = Ministry of Water & Power, being a policy making body, does not have the capacity/expertise to carry out the functions currently being performed by PEPCO

Need for an Over arching Umbrella Body

- = Complete oversight of the Power Systems on behalf of the GoP

= Liaison and coordination between the Corporate Entities (Ces) and the GOP, MLBs, USAID, Aid Giving Agencies

= Introduction of new technologies

= HRD-which cannot be taken up individually by the CEs-Transition of BPS 19 and above

= O&M studies/activity for creation of new position/facilities/offices/bifurcation of HESCO and MEPCO. Presently, and O&M study underway to reappraise the CEs HQ staffing etc.

= Fast-tracking and oversight of utilization of ADB and the World Bank loans

= Efforts to out source non-core activities

= Arranging for the Public Subscription of shares of DISCOs thru Public Offering of (available) un-sold/authorized shares

= Undertaking preliminary work for IPO of some of the CEs

= Liaison and coord between the CEs and IPPs and the Pakistan Banking Sector

= Performance Monitoring

= Performance Contracts

= Corporate Pay Scales

= Introduction of Technology (ies)

= Encouraging investments in the Power Sector, e.g. CPPs/N-CPPs/less than 50 MW IPPs - generation

= IPPs - garnering of finances

= Fulfilling financial needs

Concerns of the MLBs (specifically the ADB & the WB)

= Consider PEPCO

- ✓ As the old WAPDA-stifling for the Reform
- ✓ As inhibiting factor to the financial Independence of the CEs
- ✓ A burden for the Power Sector

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Quotation

* The greatest honour that can come to man is the appreciation and high regard of his fellow man.
H.G Mendelson

* The true test of civilization is not the census, not size of cities, but the kind fo man that the country turns out.
Ralph Waldo Emerson

* Character is made by what you stand for; reputation, by what you fall for.
Robert Quillen

* It is easier to cope with a bad conscience than with a bad reputation.
Friedrich Wilhelm

* Every man values himself more than all other men, but he always values others opinion of him more than his own.
Marcus Aurelius

* Associate yourself with men of good quality if you esteem your own reputation; for this better to be alone than in bad quality.
George Washington

* It is easier to dodge our responsibilities, but we cannot dodge the consequences of dodging our responsibilities.
Josiah Stamp

* Any women can fool a man if she wants to and if he's in love with her.
Agatha Christie

NOTES