Australian Journal of Basic and Applied Sciences, 4(3): 390-397, 2010
ISSN 1991-8178

Investigation and Congestion Management to Solve the Over-Load Problem of Shiraz Substation in FREC

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Abstract: In this paper, the transformers over-load problem of Shiraz substation in Fars Regional Electric Company (FREC) is investigated for a period of three years plan. So the suggestions for using phase shifting transformer (PST) and unified power flow controller (UPFC) in order to solve this problem are examined in details and finally, some economical and practical designs will be given in order to solve the related problems. Practical consideration and using the basic and fundamental concept of powers in transmission lines in order to find the economical design are the main advantages of this research. The simulation results of the integrated overall system with different designs compare them base on economical and practical aspects to solve the over-load and loss-reduction.

Key word: Congestion management, Phase shifting transformer (PST), Unified power flow controller (UPFC), Transmission lines, Over-load problem

INTRODUCTION

Generally, a power system can be divided into the parts of generation, transmission and distribution subsystems. In steady state, the amount of power generation and consumption are always the same and equal and the states of system are in operating point. Power in transmission lines must be in fewer amounts than maximum load ability and they must be in allowed limitation by maintaining different types of stability (Kundur, P., 2004). Also the network should have a suitable reliability regarding preservation and ability to transfer power in emergency condition such as outage of one line or transformers from network and remarkable over-load is not established in any parts of the network. Several researches have been done in theoretical and practical ways about the power regulation in transmission lines. In (Jody Verboomen, 2008), transmission power is regulated by correcting phase angle of voltage at sending-end transmission line. To improve the dynamic speed of mechanical phase shifter, a thyristor controlled static phase shifter has been used in (Krämer, A., J. Ruff, 1998; Ishigame, A., 1998; Mathur, R.M., R.S. Basati, 1981). In (Kim, J.H., B.H. Kwon, 2000), a PST has been designed to interconnect between Northern Ireland and the republic of Ireland for improving the performance of these networks. Optimal location of PST in the French network is determined by genetic algorithm in (Sweeney, R., 2001). In (Pierre Paterni, 1999) the concept of UPFC in steady state and in (Gyugyi, L., 1992; Dong, L.Y., 2002) some control strategies for UPFC are investigated.

Simulations result of FREC network show the existence of congestion and over-load in two transformers and some transmission lines related to in Shiraz substation in a three–year–plan. To do this, different design such as replacement of two transformers which exist in Shiraz substation with phase shifting transformer (PST), and some new lines establishment are done in this case. This paper is some conclusions of last researches in explanation of using PST and UPFC in different aspects in Shiraz network and solving the over – load problem. Criticizing, examining and possibility of using PST and UPFC in Shiraz network, and giving some new plans depend on economical, reliability, and scientific considerations to problem solve the over – load are the main subjects to be examined in this paper.

Investigation of Sub Transmission Network in FREC and Over-Load Problem:

There are 4 substations (230/66kv) around the Shiraz distribution network that transit consuming power of Shiraz network (Fig. 1). The amount of entered powers to Shiraz network from these substations for on-peak and off-peak of the year 2008 have been come in table.1.

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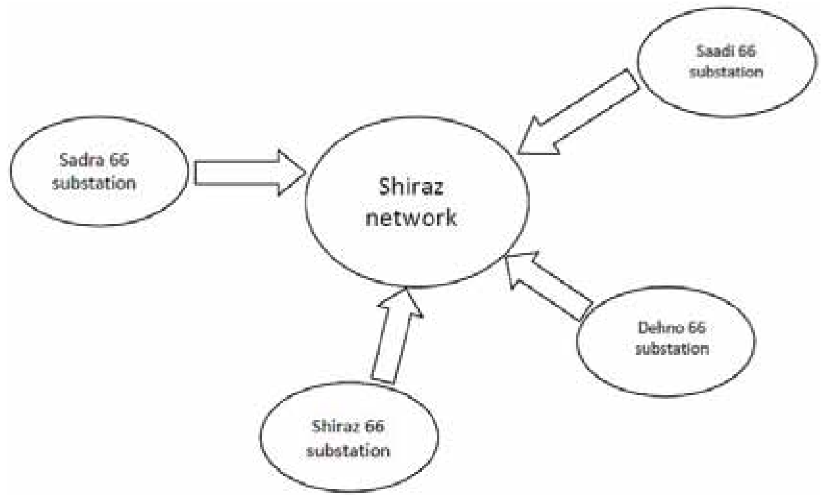

Fig. 1: Shiraz network and its substations

Table 1: Active and reactive power from substations to Shiraz network in On-peak and Off-peak load of the year 2008

Dehno 66		Saadi 66		Sadra 66		Shiraz 66		
On-peak	Off-peak	On-peak	Off-peak	On-peak	Off-peak	On-peak	Off-peak	Peak situation
122	90	126	100	86	62	218	186	P(MW)
12	16	68	44	26	6	176	127	Q(MVAR)
38.5	28.2	44.8	34,2	28.1	19.5	87.6	70.1	Loading (%)

According to table 1, it is noted that a considerable power (active and reactive) enter to Shiraz network through Shiraz substation in comparison with other substations. This subject causes over-load of the transformers of Shiraz substation and Shiraz-Hemat and Hemat –Felestin lines (Fig. 2). The results of load flow in this network for the year 2012 show the loading (275Mw, 220Mvar) which means 110% loading on each of two transformers of this substation. Although it is not reasonable, if the total reactive power is compensated in that time, the loading of each transformer will be 86%. This subject shows the importance of compensation of transmission reactive power in comparison with transmission active power from the transformers and also lacking suitable reliability in loading amount of these transformers. Furthermore, in the year 2012, the lines between Shiraz – Hemat, Hemat –Felestin and Saadi-Toorbin substations will have over-load with considerable amount of reactive power. Reducing of the active or reactive powers causes to reduce percentage transmission loading (Papic, I., 1997) and so, in order to reduce loading of system's over–load parts, each of active or reactive power must be reduced.

Investigation of Reducing Over-Load Problem and Reliability Enhancement Methods:

The main reason for over-load in two transformers of Shiraz substation and related lines is passing excessive apparent power (S) through them. This excessive power and over-load problem can be attributed to improper distribution of active and reactive power through transmission lines and transformers considering the existing condition.

Since the loading is defined as the ratio of apparent power to maximum allowable apparent power, reducing the active or reactive power will be cause to reduce the loading of existing transformers in Shiraz substation.

According to equation of:

$$P = \frac{V_1 V_2}{X} \sin \delta$$

Reducing active power can be done by reducing in voltages of two sides of line, reducing in effective voltage phase angle between two sides of line or increasing in reactance between two sides of line by parallel reactor, PST or series reactor respectively.

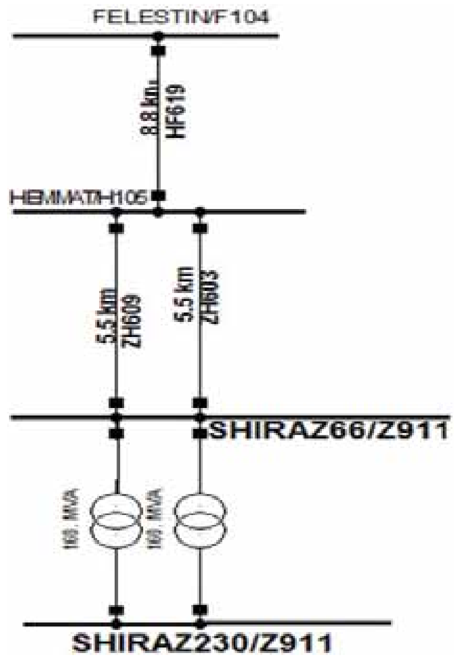

Fig. 2: Shiraz66 substation' s transformers and related over-load lines

Reducing in amount of transmission reactive power is done by generating reactive power which is required to the load by capacitors in different points of network or by reducing the tap of over-load transformers.

If another transformer is paralleled to other existing transformers, the amount of transformer loadings will decrease optimally but, such plan causes increase the short circuit level in that point and needs designing and changing related circuit breakers, protective systems and other practical considerations. That is not in our concerns.

The existence of voltage drop in different parts of the network is another problem related to over-load transformers that causes passing reactive power towards them. This reactive power transmits through transformers and its related lines and causes increase in their loading percentage. In fact, high transmission reactive power through transformers of this substation (230/66kv) towards 66kv network is because of the need of this network to the reactive power that causes voltage drop in different parts of the network and therefore reactive power flow towards them. In other words, reactive power consumption in secondary side of these transformers is one of the reasons of increasing in load of transformers and lines and voltage drop in different parts of Shiraz network. If the only purpose is to reduce over-load of transformers, there is no difference between decrease in active or reactive power through them and both two factors cause to improve the over-load condition.

In order to reduce over–load associated with loss-reduction and economic consideration, it is needed that first transmission reactive power then active power through transformers and related lines decrease. The next priority in decreasing loadings of transformers is reducing the amount of transmission active power through transformers of Shiraz substation.

According to considered basic points, in order to determine the objective function and above executive procedures that are stated according to chosen objective function, we can reduce over-load of transformers and lines in short and long period.

In short period and without any cost, changing transformers taps is the simplest way of reducing transmission reactive power and also to some extent reduces transmission active power through transformers of Shiraz substations, and over-load will be reduce a little . This causes a little decrease in voltage of network points. According to the fact that existing transformers in this substation have at most 19 taps and are set on 16, their decrease can be useful to some extent. Simulation results show that decreasing each step of tap, active and reactive power decrease 3.5 MVAR and 0.5MW in each transformer respectively.

In long period, regarding to general methods, some plans are given in next section to reduce over-load problem. In these plans, paying attention to technical points and economical aspect has a great importance.

According to the importance of using PST in order to decrease over–load, simulation results show a considerable reactive power through transformers even after installing PST. These results show that instead of each 1 percent decrease in tap of PST, active and reactive power decrease 3MW and 1MVAR respectively. This issue shows the importance of transmission reactive power in overload problem before and after PST installation.

It is obvious that applying PST in order to decrease transmission active power can have a remarkable effect in decreasing loading, if transmission reactive powers are properly distributed in the system. Reducing active power in order to decrease over–load should be in priority after decreasing reactive power through the transformers and proper distribution of reactive power in different parts of network.

Investigation and possibility UPFC Usage Possibility in Shiraz Network and Related Considerations:

In first look, according to UPFC ability in setting output active and reactive powers and setting its input bus voltage, its usage is explainable, but this plan is not suitable to Shiraz network because of following important reasons:

a) We have to use transformer with UPFC, because the voltage level must be changed from 230kv to 66kv. Therefore, two devices are linked to each other serially and the reliability of system decreases in comparison with the base state although spending a lot of. In this situation, UPFC is able to decrease the reactive power through transformer and so decreases transformers loading by producing reactive power in its output port part (the 66kv side) (IEEE Power Engineering Society, 2002).
b) The purpose of UPFC installation is to decrease transmission active and reactive power in order to decrease loading, but if transmission reactive power (176 MVAC) delivered to the network by UPFC, the operating point of UPFC is in its capacitor region that causes to improve transient stability and reduction in dynamic stability limitation (IEEE Power Engineering Society, 2002). So, although we don't have any problem in dynamic stability of this network now, according to load growth and using UPFC in mentioned area, it causes system modes to transfer into right and reaching them to jw axis and so we have the possibility of dynamic instability and we have to apply PSS on UPFC in order to damp power oscillation. This needs a complicated technology to install on UPFC.
c) It is not explainable according to economical considerations at all.
d) Using UPFC in local lines is not explainable and the only case of using it in Tie lines between main regions or different countries or areas with different electricity markets. According to above cases, doing primary researches in order to use UPFC in this regarded place does not have any technical explanation and justification.

Investigation and Possibility of Using PST in Shiraz Network and Related Considerations:

According to PST function that has the ability to change the flow of active power by inserting a series voltage in line voltage, we can reduce the over-load resulted from active power transmission through transformers of Shiraz substation. But regarding to main problems of the network, this plan cannot be considered as the first priority in solving over-load problem. Here, some points and tips related to not being the usage of PST plan in the first priority are brought in order to reduce loading.

a) The over-load can be decreased by the simple method of reducing transformer tap. This causes reduction in active and reactive power transmission.
b) It is logical to reduce transmission reactive power, before solving the active power problem. In this case, in addition to improving voltage profile in different parts of the system, losses will be reduced. Simulations show that over-load of transformers in Hemat –Felestine and Shiraz –Hemat lines is improved considerably by putting three capacitor banks in Shiraz,Hemat and Felestine, substation.
c) Using PST in the main transmission line and Tie – Line is explainable. Shiraz 230kv substation that has over-load is not considered as a Tie Line, because it is entered to this area through different lines (Fig.1).
d) If we consider different power entries to an area as main connective lines and the purpose is the improve congestion management in this area, and we don't pay attention to external part of this area, it is logical to put PST in a connective line that transmission power and heat limitation of power has a large difference in comparison with other lines. In this case, PST can reach transmission power to heat limitation, of power by improving transmission power.

Simulation result of power flow in Shiraz entering lines shows that there is not a big difference among Shiraz entering lines loadings. That means there is not a big difference between entering powers of each line and maximum loading on it. So, using PST in this area is unexplainable,

e) If the needed angle of PST which is set in operating point is great to some extent, PST function causes a large effect in the region and it is explainable. If the needed angle is small, changes performed in lines are not high, and these limited changes can be done through simpler changes in voltage or in impedance. But in any case, the reliability of PST is less than a normal transformer, and this reliability decreases due to the increase in PST phase angle.
f) According to given plans, using PST in Shiraz substation is not always optimum according to losses, over-load problem solving and being economical.
g) The experience PST using show that first, the reactive power problems are solved and then concentrate on this case. Therefore, before using PST in a network, it is required to set the power factor approximately to one.
h) The experience of using PST shows that PST is often used in advance phase angle region to increase power in transmission line. But according to this fact, PST in Shiraz is used to reduce power in transmission line or in retard phase angle region. In this case, according to the load growth, the network should be studied according to dynamic stability considerations and because of changing in short circuit level, it is necessary to examine function of protective relays.

Giving Some Plans to Reduce Loading in Shiraz Substation and its Related Lines:

According to over-loading of Shiraz substation transformers, and some related lines, the following methods are given to solve over-load problems these methods can be used individually or as another methods' complement and they can be used simultaneously.

a) Changing transformer's tap and its reduction is the simplest and cheapest method to reduce active and reactive power through transformers.
b) Implementation and usage of university substation in north of Shiraz reduces over – Loading of Shiraz – substation transformer Shiraz –Hemat line and Hemat –Felestine line and loading problem will be solved.
c) Reduction in Shiraz substation loading through increasing in Sadra substation loading. This subject is done through constructing a line from Sadra to Hemat (66kv) or Sadra to Felestine. These two plans are applicable and performable in two states. One of them with existing linkage of Shiraz-Hemat line from Shiraz substation and its providing from Sadra and the other without existing linkage. In fact, these four plans can cause a good and suitable condition according to improving reliability considerations, that one of its results is reducing loading. In other words, the main goal of giving these four plans is to improve the load ability and reliability in feeding the center of Shiraz lines from different sides. The simulated results of these plans are brought in the next section.
d) Putting capacitors in different parts of Shiraz network. According to passing a large amount of reactive power through Shiraz substation and lines, putting capacitors in different parts to reduce passing reactive components from two transformers of Shiraz substation and related lines and so reduction in loading associated with reduction in losses, is one of the most important plans that we should pay a lot of attention. Simulation results in previous plans shows that even if we perform these plans, the amount of passing reactive power is considerable and it is necessary to put capacitors in order to reduce losses not just reduce in loading. So, giving a comprehensive plan of putting capacitors in Shiraz network to improve Shiraz network condition can be a good and a very suitable and useful plan.
e) Placement of phase shifting transformer (PST) in order to reduce network losses.

Simulations results show an increase in network losses if the two Shiraz substation transformers replaced with PST. Suitable and proper placement of PST in FREC network, studying optimum load distribution and losses reduction can cause reduction in Shiraz substation transformers loadings. So, it is clear that Shiraz substation location cannot be considered as PST optimum location. Giving PST placement plan in order to reduce losses and considering constraint of loading reduction can be useful as an important plan associated with putting capacitors subject. Using PST replacement plan by optimization algorithms like genetic algorithm can be a good plan in using and applying previous experiences (Sweeney, R., 2001).

Simulation Results:

In this section, some results of performed simulations in examining several plans are given. In PST usage plan, Shiraz substation location is considered as PST location, only for over – load reduction not for loss – reduction and PST placement is not done. These plans are examined in order to obtain a comprehension and understanding in Shiraz substation over-load problem and it is necessary to decide due to economical and technical considerations:

Base plan: This plan explains existing network.

Plan 1: In this plan a line between Sadra –Hemat is added to the network in order to reduce entering power from Shiraz substation and increase entering power from Sadra to Shiraz substation.

Plan 2: In this plan a line between Sadra –Felestine is added to the network in order to decrease entering power from Shiraz substation and increase entering power from Sadra substation.

Plan 3: In this plan, the connection of Shiraz - Hemat line is removed from Shiraz substation and a line between Sadra –Hemat is added in order to decrease entering power from Shiraz substation and increase entering power of other substation specially Sadra substation.

Plan 4: In this plan, the connection of Shiraz - Hemat line is removed from Shiraz substation and a line between Sadra –Felestine is added in order to decrease entering power from Shiraz substation and increase entering power of other substations, especially Sadra substation

Plan 5: In this plan, the only change that has done due to the base state of network is placing university substation to network (Fig.3.).

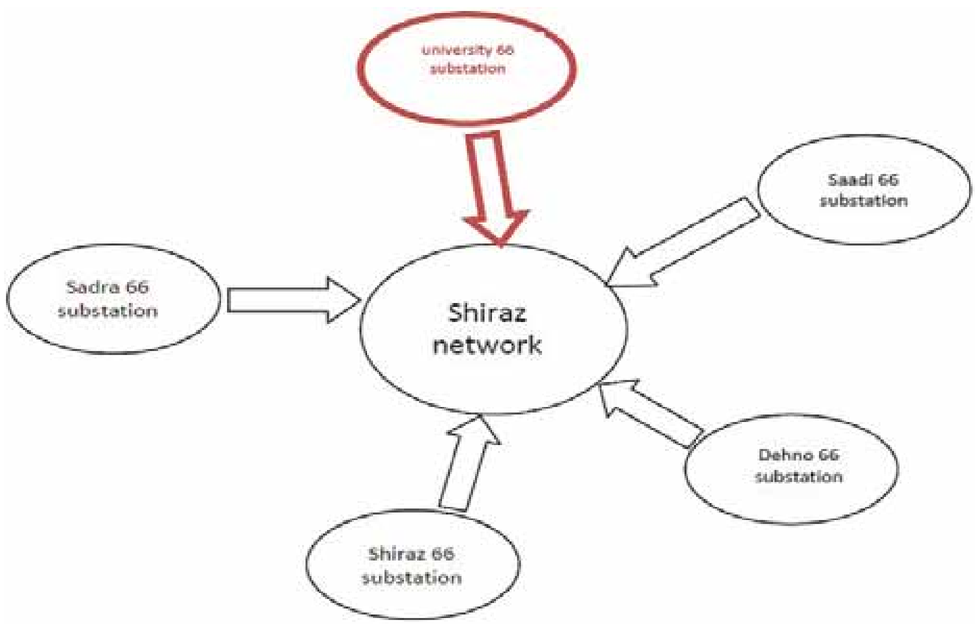

Fig. 3: university substation added to Shiraz network in plane 5,6,7,8 and 9.

Plan 6: In this plan, we add Sadra _Hemat line in addition to university substation plan.

Plan 7: In this plan, we add Sadra –Felestine line in addition to university substation plan.

Plan 8: In this plan, we add university substation and Sadra –Hemat line to the network and we separate and extract Shiraz –Hemat connecting lines.

Plan 9: In this plan, we add university substation and Sadra – Felestine line to the network and the connection of Shiraz - Hemat line is removed from Shiraz substation.

Plan10: In this plan, the only change that has done due to the base state, is replacing Shiraz substation transformers with two PST. In the base state, the voltage angle in Shiraz substation is 28.137 degrees that it comes to 24.23 degrees after putting PST.

Plan11: In this plan, the change that has done in the network due to base state, is replacing Shiraz substation's transformers with two PST when we just add university substation in this case, the voltage angle in Shiraz substation is 29.53 degrees that it becomes 24.93 degrees after putting PST, the results taken from simulation have come in tables 2 to 5.

According to simulation results, it is observed that different plans have special advantages and disadvantages, but we should select best plan due to the priorities. If the economical aspects of the plans are considered after the efficiency of the plans, we can use plans 5, 6, 7, and 8. In these three plans we should spend a lot of money because of university substation construction, but the over-load problem of lines and

Table 2: Active power of transformers and lines (MW)

	Base plan	Plan1	Plan 2	Plan 3	Plan 4	Plan 5	Plan 6	Plan 7	Plan 8	Plan9	Plan 10	Plan 11
Each transformer of Shiraz substation	109	98.7	98.6	81.8	90	83.2	80.8	81.8	82.6	82.6	61.4	50.9
Shiraz-Hemat line	32.5	24.1	24.43	-0.8	----	1.5	-2.3	-0.8	----	----	19	4.7
Felestin-Hemat line	40.4	43.1	24.4	-26	-24.5	-21.6	-19	-26	-15.8	-24.5	13.5	-15.1
Sadra-Golestan line	22	20	19.8	18.5	16.5	19.1	18.2	18.5	18.3	18.4	----	----
Sadra-Hemat line	----	19.8	----	---	----	----	10	---	8.8	----	----	----
Sadra-Felestin line	----	----	21.8	8.1	37.7	----	----	8.1	----	7.8	----	----
Each transformer of University substation	----	----	----	47.8	----	49	48	47.8	76.5	46.7	----	21.4

Table 3: Reactive power of transformers and lines (MVAR)

	Base plan	Plan1	Plan 2	Plan 3	Plan 4	Plan 5	Plan 6	Plan 7	Plan 8	Plan9	Plan 10	Plan 11
Each transformer of Shiraz substation	88	79.2	79.7	78.5	64.8	53.5	65.3	65.3	63.3	65.3	45.7	37.2
Shiraz-Hemat line	18.6	18.8	53.5	17.6	----	2.6	4.1	3.7	----	3.7	12.6	5.5
Felestin-Hemat line	32.4	32	71	30.4	7.3	0.97	-0.3	3.1	-9.2	3.1	19.6	5.7
Sadra-Golestan line	6.9	7.16	32.6	8.7	4.8	6	6.5	6.4	3.6	6.4	----	----
Sadra-Hemat line	----	4.5.-	----	----	18.6	----	-4.2	----	-1.2	----	----	----
Sadra-Felestin line	----	----	34	2.3	----	----	----	0.4	----	0.4	----	----
Each transformer of University substation	----	----	----	----	----	22.3	22.6	8.26	24.8	8.26	----	7.8

Table 4: table network losses in performing plans (KW*).*

	Base plan	Plan1	Plan 2	Plan 3	Plan 4	Plan 5	Plan 6	Plan7	Plan 8	Plan9	Plan 10	Plan 11
network Losses [kw]	137.93	138.1	79.7	138	70	138.32	138.37	138.35	138.35	138.34	143.59	39.6

Table 5: loading percentage in lines and transformers

	Base plan	Plan1	Plan 2	Plan 3	Plan 4	Plan 5	Plan 6	Plan 7	Plan 8	Plan9	Plan 10	Plan 11
Each transformer of shiraz substation	87.6	80	79.7	70	70	66.9	65.7	66.2	65.8	65.8	48.3	39.6
Shiraz-Hemat line	65.9	54.4	53.5	----	----	8.1	10.8	9.5	----	----	43.6	15.6
Felestin-Hemat line	90.4	95.5	71	27.6	47.4	37.2	32.5	45.2	31.1	44	47.7	15.6
Sadra-Golestan line	35.8	33	32.6	27	26.8	31	30	30.3	29.9	19.4	----	----
Sadra-Hemat line	----	30.7	----	65	----	----	16.7	----	13.7	----	----	----
Sadra-Felestin line	----	----	34	----	66.3	----	----	13.9	----	12.3	----	----
Each transformer of University substation	----	----	----	----	----	36.4	35.9	35.7	35.7	25.9	----	14.9

transformers solves to a large extent. If we want to consider economical aspects of the plans, plan 3 and 4 will be suitable and proper plans. Plans 10 and 11 (PST usage) are not performable because of over-load problem of lines and transformers according to the mentioned reasons and the problems will appear in the network, in future.

Conclusion:

We should examine the effects of the plan on the network in short and long periods of time. In fact, a plan is likely to be useful to the network in some aspects, but is likely to be the cause of some problems in future. In this paper, the effects of using PST and UPFC in Shiraz network was mentioned that these plans make some problems to Shiraz power network although some advantages. So, we cannot use these PST, UPFC in Shiraz power network and it is necessary to search plans that they themselves don't make problems in future, but they solve over-loading problem in some lines and transformers. In order to do this, some plans are given that solve technical problems and also have economical profit, too.

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